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# THE LIBERTY MOTOR

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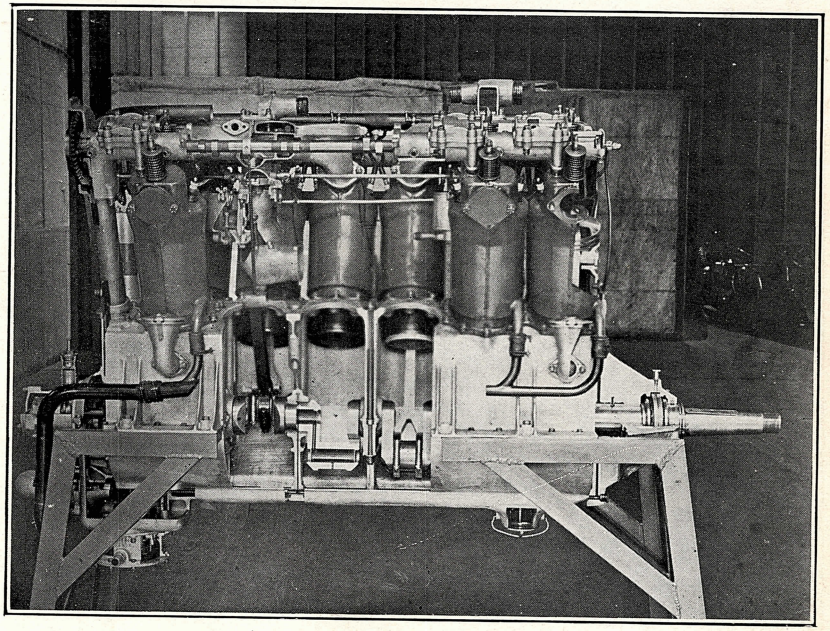
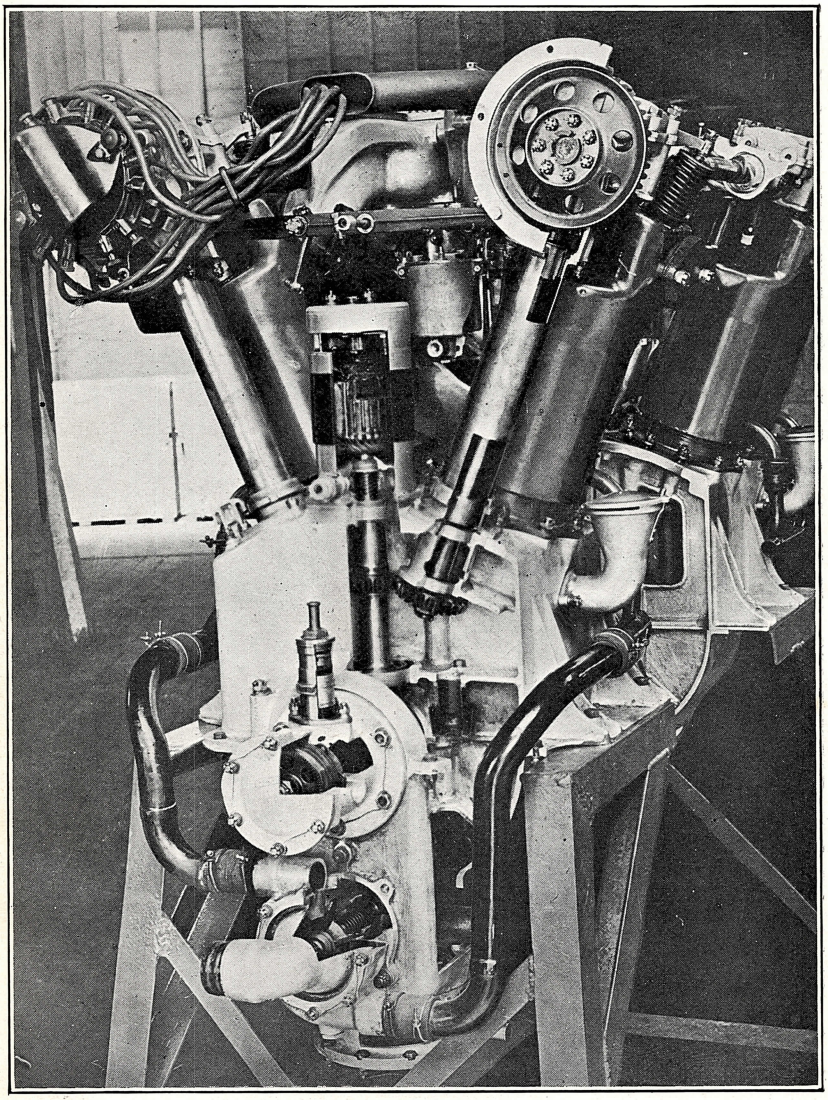


FIGURE SHOWING THE LIBERTY MOTOR.



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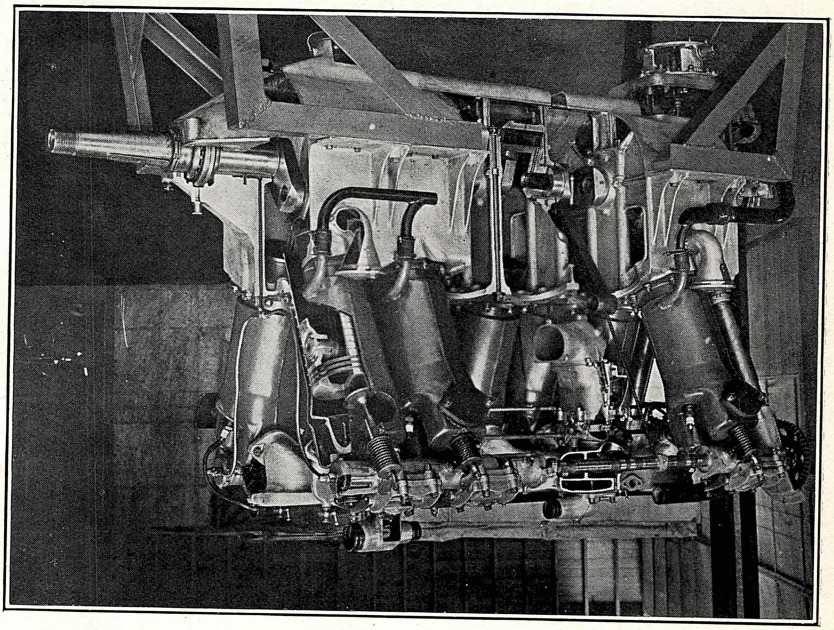

FIGURE SHOWING THE LIBERTY MOTOR.

WAR DEPARTMENT,
WASHINGTON, *August 4, 1919.*

The following publication, entitled "The Liberty Motor," is published for the information and guidance of all concerned.

[062.11, A. G. O.]

BY ORDER OF THE SECRETARY OF WAR:

PEYTON C. MARCH,
*General, Chief of Staff.*

OFFICIAL:

P. C. HARRIS,
*The Adjutant General.*

# CHARACTERISTICS OF LEADING AERO ENGINES.

| Engine. | Rated horse-power. | Type. | Number of cylin-ders. | Bore. | | Stroke. | | Bore and stroke ratio. | B. H. P. and R. P. M. at ground level. | | | | Com-pression ratio. | Piston speed, foot-minutes. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Normal. | | Maximum. | | | |
| | | | | Milli-meters. | Inches. | Milli-meters. | Inches. | | B. H. P. | R. P. M. | B. H. P. | R. P. M. | | |
| Curtiss OX5 | 90 | V-90° | 8 | 101.5 | 4.00 | 127.0 | 5.00 | 1.25 –1 | 93 | 1,400 | 95 | 1,450 | 4.5 | 1,166.0 |
| Curtiss VX | 160 | do | 8 | 127.0 | 5.00 | 177.8 | 7.00 | 1.41 –1 | 206 | 1,350 | 214 | 1,450 | 4.71 | 1,575.0 |
| Liberty 8 | 270 | V-45° | 8 | 127.0 | 5.00 | 177.8 | 7.00 | 1.40 –1 | 270 | 1,700 | 285 | 1,850 | 18 p. ct. | 1,980.0 |
| Liberty 12A | 400 | do | 12 | 127.0 | 5.00 | 177.8 | 7.00 | 1.40 –1 | 400 | 1,700 | 430 | 1,800 | 18 p. ct. | 1,980.0 |
| Hispano Suiza | 150 | V-90° | 8 | 120.0 | 4.72 | 130.0 | 5.12 | 1.08 –1 | 150 | 1,450 | 170 | 1,700 | 4.8 –1 | 1,240.0 |
| Do | 180 | do | 8 | 120.0 | 4.72 | 130.0 | 5.12 | 1.08 –1 | 180 | 1,700 | 205 | 1,800 | 5.3 –1 | 1,450.0 |
| Do | 300 | do | 8 | 140.0 | 5.5 | 150.0 | 5.90 | 1.07 –1 | 300 | 1,600 | 340 | 1,800 | 5.3 –1 | 1,578.0 |
| LeRhone | 80 | Rotary | 9 | 106.0 | 4.13 | 140.0 | 5.51 | 1.32 –1 | 80 | 1,200 | 85 | 1,300 | 1.33–1 | 1,100.0 |
| Gnome | 100 | do | 9 | 110.0 | 4.33 | 150.0 | 5.90 | 1.36 –1 | 103 | 1,200 | 110 | 1,300 | 4.0 –1 | 1,180.0 |
| ABC Wasp | 170 | Radial | 7 | 114.3 | 4.5 | ..... | 5.9 | 1.31 –1 | 170 | 1,750 | 200, | 1,850 | 4.025 | 1,690.0 |
| ABC Dragon-Fly | 320 | do | 9 | 140.0 | 5.5 | 165.0 | 6.5 | 1.18 –1 | 320 | 1,650 | 350 | 1,750 | 4.025 | { 1,785.5 / 1,650.0 |
| BR1 | 150 | Rotary | 9 | ..... | 6.72 | ..... | 6.66 | 1.42 –1 | 154 | 1,250 | 156 | 1,300 | 5.9 –1 | 1,394.0 |
| BR2 | 200 | do | 9 | ..... | 5.51 | ..... | 7.08 | 1.285–1 | 238 | 1,300 | 242 | 1,350 | 5.3 –1 | 1,475.0 |
| Beardmore | 160 | Vertical | 6 | 142.0 | ..... | 175.0 | ..... | 1.23 –1 | 178 | 1,350 | 192 | 1,450 | 4.56–1 | 1,435.0 |
| Galloway | 240 | do | 6 | 145.0 | 5.71 | 190.0 | 7.48 | 1.31 | 236 | 1,400 | 250 | 1,500 | 4.96–1 | 1,558.0 |
| Siddeley | 240 | do | 6 | ..... | 5.71 | ..... | 7.48 | 1.31 | 240 | 1,400 | 250 | 1,500 | 5.0 –1 | 1,558.0 |
| Hispano | 150 | V-90° | 8 | ..... | 4.72 | ..... | 5.12 | 1.08 –1 | 156 | 1,500 | 165 | 1,600 | 4.8 –1 | 1,280.0 |
| Do | 180 | do | 8 | ..... | 4.72 | ..... | 5.12 | 1.08 –1 | 220 | 2,000 | 225 | 2,100 | 5.3 –1 | 1,707.0 |
| Rolls-Royce Falcon 3 | 220 | V-60° | 12 | ..... | 4.00 | ..... | 5.75 | 1.44 –1 | 270 | 2,200 | 280 | 2,300 | 5.3 –1 | 2,108.0 |
| Rolls-Royce Eagle 8 | 360 | do | 12 | ..... | 4.5 | ..... | 6.5 | 1.44 –1 | 350 | 1,800 | 360 | 1,900 | 5.3 –1 | 1,950.0 |
| Sunbeam Arab | 200 | V-90° | 8 | 120.0 | 4.72 | 130.0 | 5.12 | 1.08 –1 | 217 | 2,000 | 224 | 2,100 | 5.3 –1 | 1,710.0 |
| Sunbeam Maori | 250 | V-60° | 12 | ..... | 3.94 | ..... | 5.31 | 1.35 –1 | 265 | 2,100 | 280 | 2,200 | 5.6 –1 | ..... |
| Sunbeam Cossack | 320 | do | 12 | ..... | 4.33 | ..... | 6.30 | 1.45 –1 | 350 | 2,000 | 364 | 2,100 | 5.0 –1 | 2,100.0 |
| Clerget 92 | 110 | Rotary | 9 | 120.0 | 4.72 | ..... | 6.30 | 1.33 –1 | 122 | 1,250 | 123 | 1,300 | 4.36–1 | 1,260.0 |
| Do | 130 | do | 9 | ..... | 4.72 | ..... | 6.30 | 1.33 –1 | 127 | 1,250 | ..... | ..... | 4.56–1 | 1,312.0 |
| Hispano | 180 | V-90° | 8 | ..... | 4.72 | ..... | 5.12 | 1.08 –1 | 208 | 2,000 | 225 | 2,100 | 5.3 –1 | 1,707.0 |
| Do | 200 | do | 8 | ..... | 4.72 | ..... | 5.12 | 1.08 –1 | 220 | 2,000 | 215 | 2,100 | 4.8 –1 | 1,707.0 |
| Lorraine Dietrich | 275 | do | 8 | 120.0 | 4.72 | 175.0 | 6.89 | 1.46 –1 | 278 | 1,650 | ..... | ..... | ..... | ..... |
| Fiat A12bis | 275–300 | Vertical | 6 | 160.0 | 6.3 | 180.0 | ..... | 1.12 | 304–290 | 1,600 | 325 | 1,760 | 4.31–1 | 1,653.0 |
| Fiat A14 | 600 | do | 12 | ..... | 6.69 | ..... | 8.27 | 1.235–1 | 700 | 1,500 | 725 | 1,600 | ..... | ..... |
| I. F. V5 | 200 | do | 8 | 130.0 | ..... | 190.0 | ..... | ..... | 250 | 1,400 | 268 | 1,600 | 5.0 | 1,995.0 |
| Spa 6A | 200 | do | 6 | 135.0 | ..... | 170.0 | ..... | ..... | 210 | 1,600 | 225 | 1,700 | 5.0 | 1,895.0 |
| Benz | 220 | Vertical | 6 | 145.0 | ..... | 190.0 | ..... | ..... | 230 | 1,400 | 252 | 1,650 | 4.93 | 1,745.0 |
| Maybach | 200 | do | 6 | 150.0 | ..... | 190.0 | ..... | ..... | 200 | 1,200 | ..... | ..... | ..... | 1,496.0 |
| Mercedes | 160 | do | 6 | 140.0 | ..... | 160.0 | ..... | ..... | 150 | 1,250 | ..... | ..... | 4.8–4.52 | 1,312.0 |
| Do | 260 | do | 6 | 160.0 | ..... | 180.0 | ..... | ..... | 252 | 1,400 | 260 | 1,500 | 4.94 | { 1,635.0 / 1,400.0 |
| Oberursel | 110 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |

| Engine. | Order of firing. | Method of cooling. | M. E. P. pounds per square inch. | Valves per cylinder. | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Inlet. | | | | Exhaust. | | | |
| | | | | Number. | Diameter (inches). | Total area (square inches). | Lift (inches). | Number. | Diameter (inches). | Total area (square centimeters). | Lift (inches). |
| Curtiss OX5 | 1L, 1R, 2L, 2R, 4L, 4R, 3L, 3R | W | 111.00 | 1 | 1.9094 | 2.0623 | 0.3437 | 1 | 1.9094 | 2.3267 | 0.3878 |
| Curtiss VX | do | do | 110.00 | 1 | 2.7559 | 3.2366 | .3740 | 1 | 2.7559 | 3.2366 | .3740 |
| Liberty 8 | | do | 115.00 | 1 | 2.5 | 3.4344 | .4375 | 1 | 2.5 | 2.9437 | .3750 |
| Liberty 12A | 1L, 6R, 5L, 2R, 3L, 4R, 6L, 1R, 2L, 5R, 4L, 3R | do | 115.00 | 1 | 2.5 | 3.4344 | .4375 | 1 | 2.5 | 2.9437 | .3750 |
| Hispano Suiza | 1L, 4R, 2L, 3R, 4L, 1R, 3L, 2R | do | 114.00 | 1 | 1.9685 | 2.4350 | .3937 | 1 | 1.9685 | 2.4350 | .3937 |
| Do | do | do | 122.00 | 1 | 1.9685 | 2.9350 | .3937 | 1 | 1.9685 | 2.4350 | .3937 |
| Do | do | do | 125.00 | 1 | | | | 1 | | | |
| LeRhone | 1, 3, 5, 7, 9, 2, 4, 6, 8 | A | 81.00 | 1 | 1.5629 | 1.7313 | .3593 | 1 | 1.5629 | 1.4492 | .2952 |
| Gnome | do | do | 88.70 | | | | | 1 | | | |
| ABC Wasp | 1, 3, 5, 7, 2, 4, 6 | do | 115.00 | 1 | 2.17 | 3.33 | .4700 | 2 | 1.338 | 2.4800 | .2950 |
| ABC Dragon-Fly | 1, 3, 5, 7, 9, 2, 4, 6, 8 | do | 114.00 | 1 | 2.6559 | 5.4537 | .6535 | 2 | 1.6929 | 2.2992 | .4330 |
| BR1 | do | do | 94.00 | 1 | 1.77 | 2.41 | .4300 | 1 | 2.000 | 2.7300 | .4300 |
| BR2 | do | do | 95.20 | 1 | 2.47 | 3.9554 | .5100 | 1 | 2.28 | 3.6510 | .5100 |
| Beardmore | 1, 5, 3, 6, 2, 4 | W | 103.00 | 1 | 2.559 | | | 1 | 2.5590 | | |
| Galloway | do | do | 116.00 | 1 | 2.7165 | 4.0455 | .4724 | 2 | 1.8110 | 4.2346 | .4724 |
| Siddeley | do | do | 118.10 | 1 | 2.5984 | 3.9060 | .4724 | 2 | 1.7322 | 5.2080 | .4724 |
| Hispano | 1, 4, 2, 3, 4, 1, 3, 2 | do | 114.75 | 1 | 1.9685 | 2.4350 | .3937 | 1 | 1.9685 | 2.4350 | .3900 |
| Do | do | do | 121.80 | 1 | 1.9685 | 2.4350 | .3937 | 1 | 1.9685 | 2.4350 | .3900 |
| Rolls-Royce Falcon 3 | Rht. 1, 2, 5, 4, 3, 1, 6, 5, 2, 3, 4, 6 | do | 114.00 | 1 | 1.7496 | 2.4211 | .4437 | 1 | 1.7496 | 2.4211 | .4400 |
| Rolls-Royce Eagle 8 | do | do | 124.00 | 1 | 2.0000 | 2.9155 | .4850 | 1 | 2.0000 | 2.9155 | .4800 |
| Sunbeam Arab | 1, 1A, 2, 2A, 4, 4A, 3, 3A | do | 115.00 | 1 | 2.126 | 2.3631 | .3543 | 2 | 1.2598 | 2.8088 | .3543 |
| Sunbeam Maori | 1, 5, 3, 6, 2, 4 | do | 125.00 | 2 | | | .3543 | 2 | | | .3500 |
| Sunbeam Cossack | do | do | 124.00 | 2 | 1.6142 | 3.6952 | .3543 | 2 | 1.6142 | 1.8476 | .3500 |
| Clerget 92 | 1, 3, 5, 7, 9, 2, 4, 6, 8 | A | 78.00 | 1 | 1.5748 | 1.9423 | .3937 | 1 | 1.9685 | 2.8031 | .4528 |
| Do | do | do | 81.00 | 1 | 1.692 | 2.24 | .3900 | 1 | 1.9685 | 3.038 | .4527 |
| Hispano | 1, 4, 2, 3, 4, 1, 3, 2 | W | 121.80 | 1 | 1.9685 | 2.4350 | .3900 | 1 | 1.9685 | 2.4350 | .3931 |
| Do | do | do | 115.00 | 1 | 1.9685 | 2.4350 | .3900 | 1 | 1.9685 | 2.4350 | .3937 |
| Lorraine Dietrich | | | | | | | | | | | |
| Fiat A12bis | 1, 5, 3, 6, 2, 4 | W | 105.00 | 2 | 2.00 | 5.5180 | .4300 | 2 | 2.0078 | 5.518 | .4375 |
| Fiat A14 | | do | 108.00 | | | | | | | | |
| I. F. V5 | | do | 107.60 | | | | | | | | |
| Spa 6A | | | 116.60 | | | | | | | | |
| Benz | | W | 113.00 | | | | | | | | |
| Maybach | | do | 107.40 | | 2.244 | | | | 2.244 | | |
| Mercedes | | | 105.20 | | 1.8998 | | | | 1.3779 | | |
| Do | | | 107.50 | | | | | | | | |
| Obernrsel | | | | | 2.3622 | | | | 2.3622 | | |

# CONTENTS.


CHAPTER I.

History of the Liberty motor: Page.

Introductory 9
Building an American motor instead of a foreign one 9
The foremost American engineers were called together 10
Experimental tests 10
Manufacturing 11
Service 12
Reliability and efficiency of the Liberty 12
Further evidence of reliability 13

CHAPTER II.

Liberty construction features:

Preface 15
45-degree cylinder angle 15
Type of cylinders 16
Ignition system 21
Carburetion 22
Lubricating system 26
Cooling system 30
Overhead cam shaft 31
Connecting rods 33
Pistons 34
Crank shaft 34
Spark plugs 36

CHAPTER III.

Proper disassembly and inspection of the Liberty motor:

Use of tools and methods of working 38
Remove spark plugs 39
Check timing and tappet clearances 39
Examine and remove ignition system 41
Dismounting generator 42
Disassembly and replacing work parts 43
Remove carburetors 44
Remove water outlet headers 44
Remove intake manifolds 44
Remove cam-shaft housing units 45
Removal of cam shaft 45
Replacing cam shaft 46
Generator and lower-cam shaft drive shaft assemblies 47
Remove cooling system connections 47
Remove water pump 47

Proper disassembly and inspection of the Liberty motor—Contd. Page.
Assemble pump 48
Remove cylinders 48
Remove, inspect, and grind valves 49
Connecting rod and piston overhaul 51
Disassembly of crank case 52
Care and fit of bearings 53
Connecting-rod inspection and overhaul 54
Crank-shaft inspection and overhaul 56
Removing the hub 57
Lower cam-shaft drive shafts and generator drive-shaft assembly 57
Water-pump bevel drive gear 58
Oil-pump disassembly and inspection 58

CHAPTER IV.

Reassembly of the Liberty motor:
Work preliminary to reassembly 60
Crank-shaft placing 60
Placing connecting rod and piston assemblies on crank shaft 61
Assemble two halves of crank case 61
Place water-pump bevel driver 62
Install oil pump 62
Turn crank case right side up 62
Install generator drive-shaft assembly and two lower cam-shaft drive shafts 62
Place all cylinders 62
Aligning cylinders by use of straight edge 63
Place intake manifolds 63
Install water-outlet headers 64
Install carburetors 64
Install cam-shaft housing assemblies 65
Install water pump 65
Put on water-inlet manifolds 66
Put on crank-case breathers 66
Timing of cam shaft 66
Installing ignition 69

CHAPTER V.

The Liberty starter 73

# THE LIBERTY MOTOR.

## CHAPTER I.

## HISTORY OF THE LIBERTY MOTOR.

### INTRODUCTORY.

At the time of the entry of the United States into the war, the Allies' air forces still were supreme, though at times it appeared that their greatest possible efforts could barely surpass those of the enemy. It was therefore apparent that we should use all haste in putting into effect the greatest aviation program possible to positively assure control of the air. Numbers of the greatest men from our mechanical and engineering institutions were called upon for advice and aid, and in an almost incredibly short time our Government had under way a gigantic aviation program. As we were interested here solely in the Liberty motor, it is needless to discuss other parts of this huge aviation program, but it is important that we realize and understand how great a part the Liberty motor has played, and how important a contribution it was to the air service of the Allies.

### BUILDING AN AMERICAN MOTOR INSTEAD OF A FOREIGN ONE.

It was readily understood that we could not hope to build motors on the same plan as our Allies in any quantity, for our methods were entirely different from theirs. A single motor produced by them was the results of many weeks' skilled labor by expert mechanics, mainly handwork, but slow and expensive to produce. Our manufacturing methods, chiefly owing to the demands of the automotive industry, had been developed along entirely different lines, so that we eliminated nearly all the tedious hand work and designed special machinery capable of turning out very rapidly great quantities of parts. Owing to the fact that these parts were fine machine productions, very accurately calibrated, they were interchangeable, making it possible to produce various parts in different factories and building them into the finished product at still other factories. As may be readily seen, it would have been rather difficult to adapt our methods to the production of some of the foreign types of motors, and it was found practically impossible to undertake production here of the one type and size most needed.

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### THE FOREMOST AMERICAN ENGINEERS WERE CALLED TOGETHER.

After a rather hurried consultation of some of our foremost engineers, it was decided that the best plan would be to design an entirely new motor, having the required horsepower and which could be placed on a production basis in a very short time. For the purpose of designing this motor, a board was organized having as its membership a number of men who were known to be the most capable engineers and designers connected with our automobile and gas engine industry, and the problem of producing this design in a very short time was put up to them with absolute confidence in their ability to solve the problem successfully. Before starting their work, a few certain well-defined points were to be kept in mind and beyond these they were to use their own judgment entirely:

First. The motor must develop around 400 horsepower, with a weight of not over 2½ pounds to the horsepower, and as much lower as would be consistent.

Second. No experimental ideas were to be tried, as the time was too valuable to be wasted on experiments which showed the least possible chance of a failure.

Third. The motor must be adapted to our modern factory production methods, so that it could be produced rapidly and in great quantities at as low a cost as possible, after all other points had been considered.

With these three factors before them, the men delegated to this important undertaking set to work to produce what we now know as the Liberty motor. The first motor was of 8-cylinders, that being thought sufficiently large for the requirements, but before going far, it was decided to build a larger motor, so that the plans were changed to a 12-cylinder type. This type, as we know, proved to be what was required most at the time. Later on, a demand was made for the 8-cylinder type, which would have been under production also in a very short time. Though we entered the war in April, 1917, and some little time had elapsed before the design of the motor could be commenced, the first complete motor was delivered for operation on July 4, 1917, which was truly a remarkable achievement and without precedent in the history of the gasoline engine.

### EXPERIMENTAL TESTS.

After designing and building the original motors, they were subjected to every conceivable test and experiment, to prove out thoroughly every feature so that there would be no possibility of a failure after production was begun. For instance, various types of carburetors were tested and the final type accepted proved to be the

most reliable and efficient under all conditions. Likewise, various ignition systems were given all possible consideration and the one showing the most desirable features finally adopted. As the motors were created to make possible tests artificial atmospheric conditions were created to make possible tests of running conditions that might be expected in actual service. Not entirely satisfied with these tests, and to carry them still further, a motor was sent to the top of Pikes Peak and carefully tested out at an altitude of 14,000 feet, as well as at different altitudes below that point. Every available kind of lubricant was tried under various conditions, many types of spark plugs tested, various kinds of bearing metal, valve metal, pistons, and other parts entering into the motor were given the most exhaustive scientific and working tests, proving out every feature that had been decided upon as the best of many to be had for the choosing. It is needless to attempt to discuss all the various tests and experiments which led to the final adoption of the Liberty motor as we now know it. It is truly remarkable, though, that in such a very short time so great a task could be completed and so few changes be found necessary after the final plans were adopted.

### MANUFACTURING.

After the final plans were adopted, tests made and authority granted to produce in quantities, the various manufacturers were consulted on the actual production. As the Packard Motor Co. had done most of the work on the experimental motors, they were in a position to almost immediately undertake a contract for 6,000 motors. They were the first to commence production, shipping the first complete flying motor on Thanksgiving Day of 1917 and gradually increasing their output until a total of 5,000 motors had been shipped by November 21, 1918. The Lincoln Motors Co. was second to begin production, building in record time an entirely new factory, modern in every respect, and fitted with millions of dollars' worth of the very best machinery for producing the motors. The Ford Motor Co. was third to begin production of the completed motors, but was producing quantities of some parts to supply the other factories, nearly as soon as any motors were produced by any of them. In fact, to Ford belongs the credit for developing the peculiar process of manufacturing the cylinders which had so much to do with speeding up the production of the other factories.

The Nordyke-Marmon, General Motors, and Trego Motors Corporation were also contracted to manufacture Liberty motors, so there were in all six large factories devoting the greater part of their efforts to the manufacture of the motors complete and many other factories devoting at least a part of their output to various parts and accessories to be assembled into the complete motors.

### SERVICE.

The Liberty motors produced were shipped to France, England, and Italy in quantities, and all agreed that no other motor was more reliable, efficient, and desirable for the particular purpose than they. England used them successfully in their De Haviland and Handley-Page airplanes, which were two of the very best of their types, and Italy found them well adapted to the giant Caproni, the dreadnaught of the air. Great numbers of them were installed in our American De Haviland, which is a most successful type of plane, and a number had been tried successfully in the American twin-motored Handley-Page. Both of these planes are adopted from the English designs and built in our new factories here. They were also used to a certain extent in other types of planes, and the new eight-cylinder type of motor would have been well adapted to the Bristol, as well as a number of other planes requiring less horsepower than the De Haviland and more than most of the other aviation motors could deliver.

### RELIABILITY AND EFFICIENCY OF THE LIBERTY.

As examples of the reliability and efficiency of the Liberty motor, a few details of some tests recently carried out on a flying field are given. Though the results of these tests were not published for the public, every student of the Liberty motor should know of them, as they will thereby have greater confidence in the motor, and undoubtedly feel greater interest in working on them. A motor which came from the factory among a shipment of several picked at random and no different from any other stock motors was given a test under actual flying conditions to determine just how much service it would give before it was necessary to overhaul it. This motor was installed in a Curtiss R–4 airplane and used continually, day after day, for flights of from a few minutes up to several hours, on cross-country trips, until it had been through over 160 hours of flying extending over about two months time. During this time the motor was given no more care and attention than any other would receive in actual service on the field, such as the usual inspection before each flight and possibly a few slight minor adjustments. Through this entire test period this motor was never out of commission at any time, never made a forced landing, or had any serious defect show up in any way. There was practically no spark-plug trouble, the original set of plugs being used during the first 48 hours of flying before removal, and then all were still in good condition. The average gasoline consumption for the 160 hours was less than 20 gallons per hour. The fact that castor oil was used may account for this low consumption to a certain extent.

When this motor was torn down for inspection and overhaul, it was found to be in such good condition that it would have withstood a number of hours additional flying time without developing any serious trouble. The crank shaft main bearings were all in good condition, none being out of round a maximum of 0.001 inch, with no scored or roughened surfaces. The crank pins were likewise in very good condition, none being out of round more than 0.0015 inch, and all surfaces in good condition. This crank shaft, after 160 hours' running, was in nearly perfect condition and fit to be placed in service again immediately. All main-bearing journals were in good condition except what might be expected from ordinary wear and a slight tendency to cracking shown by one lower half. This one half was in such condition though, that it would have stood up for a great number of hours under ordinary conditions. The connecting-rod forked end bearings showed some signs of cracking on their inner surfaces and the usual amount of wear to be expected, but were still in such condition that they would have stood up for a number of hours. All pistons were in good condition, showing only ordinary wear and the slight tendency to scoring as usual, with aluminum alloy pistons. The carbon deposit on pistons and in cylinders was very slight considering the running time, and all cylinder walls were in perfect condition, the maximum out of round being but 0.002 inch. All intake valves of this motor were still gas-tight and exhaust valves showed but slight leaks, none being pitted badly or burned, and valve guides showing but ordinary wear. The valve springs were all in good condition. The cam shaft and rocker arm assemblies were in good condition, the only noticeable wear being on some of the cam-roller pins which had worn considerably in some cases, owing to the loosening up of the bushing, throwing the wear onto the pin, which was too soft to carry it. The only trouble experienced with the ignition was two broken leads in the generator found after the motor was in the shop and slightly excessive wear on the splines of the generator-drive shaft, due to the metal being slightly soft or possibly to improper fitting. Both upper and lower halves of crank case were in perfect condition and showed no distortion whatever. Considering the very light weight of this case in proportion to the great horsepower of the motor, its design and construction can readily be seen to be as near perfection as it is possible to build such a case.

### FURTHER EVIDENCE OF RELIABILITY.

Another motor, run at the same time as this one and under exactly similar conditions, was in very good condition at the time of tear down, but showed slightly more wear all round. This motor used a heavy mineral oil instead of castor and apparently as good results were

had from it, though the wear was slightly more, especially on the bearings, which would indicate that castor is a better lubricant than mineral oil. The difference in cost, however, more than overcomes the slight advantage gained by its use. This motor also used slightly more gasoline and oil than the other. As the jets used were larger than those of the first motor, the gasoline consumption is accounted for. These tests, together with reports of service in many places and under all conditions, prove conclusively that the motors as now manufactured, are not only capable of long life in service, but are entirely dependable, and very efficient. As a result of these facts, it has been decided that Liberty motors may be run for periods of 125 to 150 flying hours before tearing down or overhauling, which is a much longer time than was formerly customary with other motors, and as long a time as it has ever been considered possible to run even the best types of aviation motors. Taking into consideration all these things, we can truthfully say that the Liberty motor is not only a wonderful motor, but one we may well be proud to claim as a product of American genius and industry and the best of its type and power built anywhere during the time since aviation motors have been in use.

## Chapter II.

# LIBERTY CONSTRUCTION FEATURES.

### PREFACE.

In consideration of this chapter, it is not to be held as a complete description of the Liberty motor, nor as covering every detail of the motor. In chapter 3 on "Disassembly and inspection of the Liberty motor," and in chapter 4, "Reassembly of the Liberty motor," practically all details of the motor, in so far as the mechanic is concerned, are covered.

Only such details and features are taken up here as are peculiar to this particular motor or such as it is thought necessary to explain fully in order to give the student mechanic a more thorough understanding of the motor than might be gained from just ordinary work on it.

Although it is true that the designers of the Liberty did not create any entirely new features but rather adapted and applied only ideas which had been tried and proven on other motors of various types, they did make some rather radical departures from the ordinary aviation motors with which we are familiar and such will be taken up here for explanation.

### FORTY-FIVE-DEGREE CYLINDER ANGLE.

Perhaps the most outstanding feature, or the one that seems most peculiar to the student at first, is the cylinder angle of 45° instead of the usual 60° at which ordinary 12-cylinder motors have the cylinders set. This feature is one on which there has been much discussion, and on which there is perhaps room for much argument, if the mechanic cares to go into the more technical points of design and operation.

As it is not necessary, and of no practical value to the mechanic to go into these deeper and more complicated details, no attempt will be made here to settle any of these argumentative points, but rather an attempt will be made to explain the reasons and ideas the designers had in mind when creating the motor.

One of the first considerations to be made in designing the Liberty motor was its adaptability to existing designs of fuselages, if possible without it being necessary to alter them to any extent. Had the

motor been designed with the ordinary 60° angle it would have taken up a much wider space than the design that was adopted and would have made necessary the designing of new fuselages, which, owing to the width required, would not have been as efficient as the present types.

We may say then that the chief reason for placing Liberty cylinders at a 45° angle was to make the motor more compact and easily adaptable to existing types of airplanes. It will be readily understood by any student who has paid any attention to the study of aerodynamics that a wider fuselage would offer greater head resistance to the air stream and this extra drift would consume some power, lowering the efficiency of the airplane.

No doubt the item of vibration was taken into account also, and it appears that what is known as directional vibration is eliminated to a great extent by the uneven firing order resulting from the 45° angle. Such points as this, however, can profitably be overlooked by the student mechanic, as they but lead to useless argument and consume class time that might be employed to better advantage gaining information which is of real practical value to the mechanic.

Setting the cylinders at a 45° angle, using the ordinary 120° throw crank shaft, causes an uneven period between firing points which is at first rather confusing to the student, but may be easily understood when once explained.

The diagrams shown here ought to bring out this point very clearly, it being seen that when a piston on the left bank has passed top center at the beginning of the power stroke; for example, the crank throw at the same angle carrying the next piston to pass top center beginning the power stroke on the right bank, must travel exactly 45° before reaching the same relative position.

As the crank throws are of 120°, it must be apparent now that before another piston on the left bank can reach top center beginning the power stroke, the crank next to come up will have to travel the remainder of the 120°, which is 75°, it already having moved 45° from its position at the beginning.

By repeating this process through the complete revolution of 360° or 3 crank-throw angles, we find that 6 cylinders have passed the firing point, and after 2 revolutions of the crank shaft all 12 cylinders have fired, completing the entire cycle.

### TYPE OF CYLINDERS.

The peculiar type of cylinder construction of the Liberty is worthy of note, as it is a departure in several ways from any other with which we have come in contact and is considered to be the most successful type ever built for aviation motors.

Its light weight, together with very great strength, makes it far superior to any other type of cylinder for the purpose. At first it was thought impossible to manufacture it in the quantities needed, but a special process of forging from drawn steel tubing was evolved, which simplified and cheapened as well as speeded up the

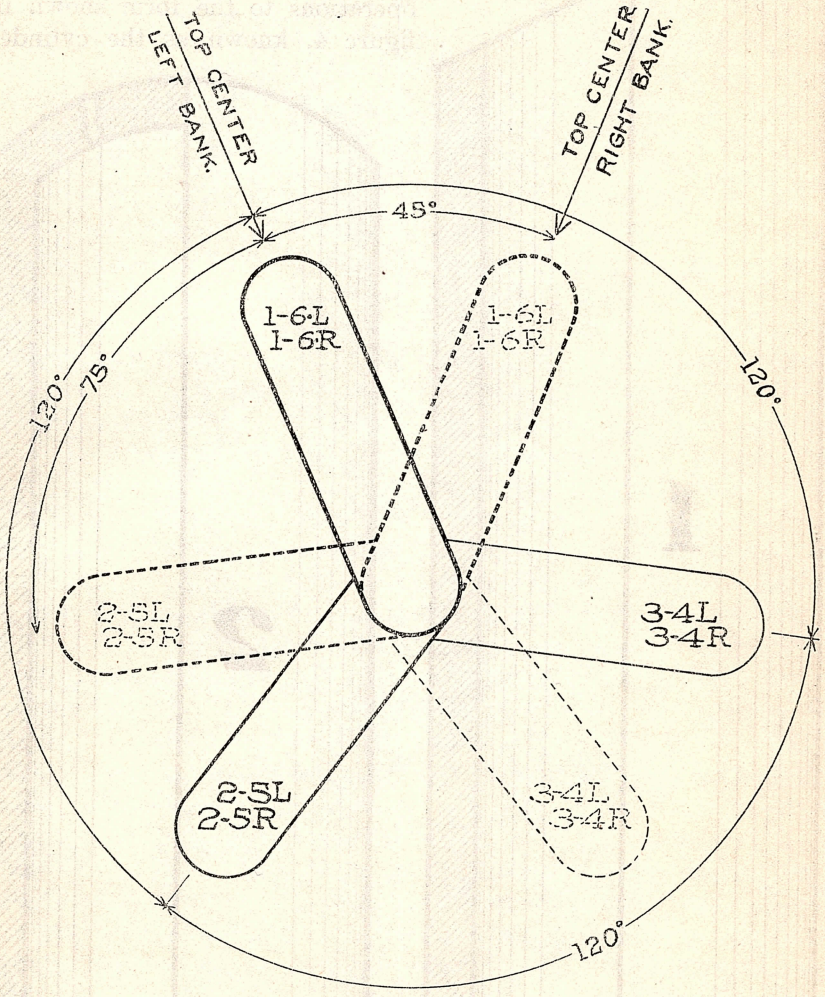



FIG. 1.

production, and in a very short time enough forgings had been completed for several thousand motors.

The drawings shown here will convey to the mind of the student the process used in producing Liberty cylinders, from the beginning as a section of drawn steel tubing to the completed cylinder ready

for assembly into the motor. All the many manufacturing details can not be explained in detail here, but a general idea will be given.

Special machines were designed and built to handle the forging process, which rapidly change the length of tubing in three short operations to the form shown in figure 4, known as the cylinder

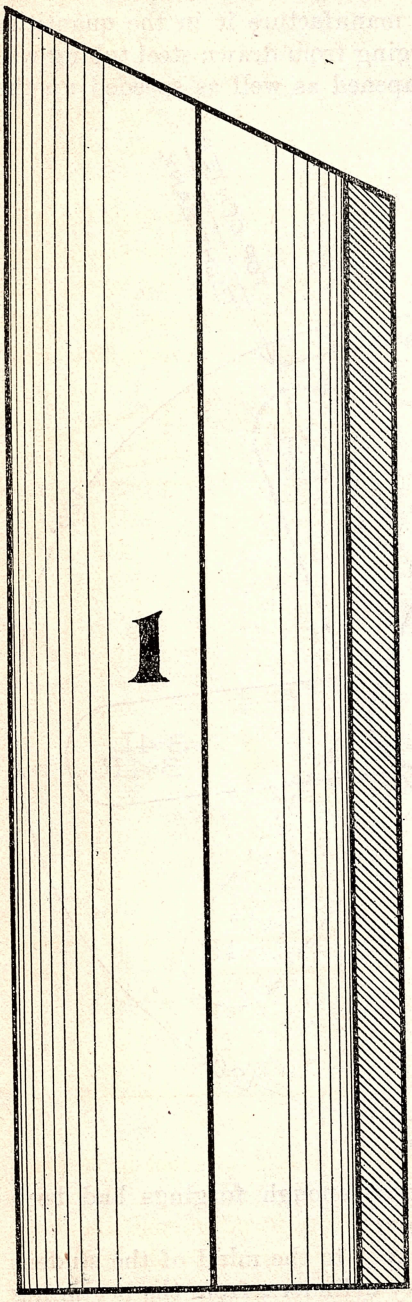



FIG. 2a.

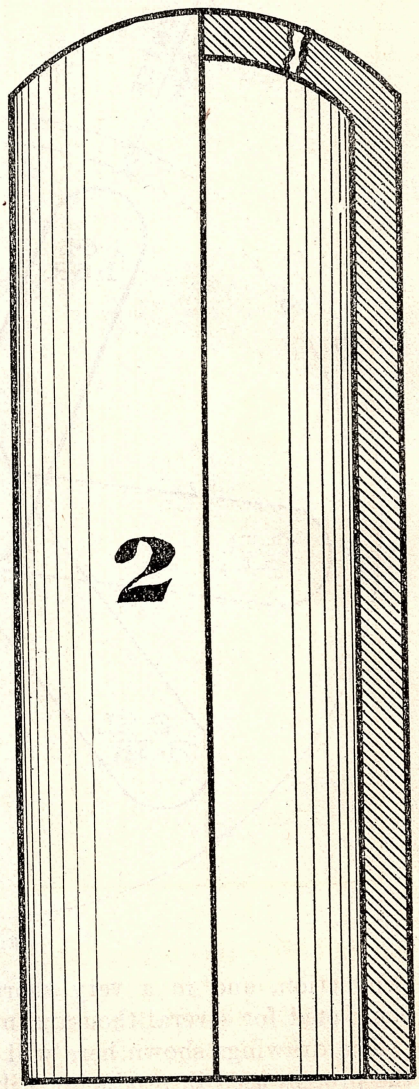



FIG. 2b.

forging. It will be noted that the head of this cylinder forging is one solid piece with the walls, the forging process simply folding

the end in, leaving absolutely no seam or weak spot. It will also be noted that the flange is produced by an upsetting process, leaving no seam or joint at all.

The rough forging weighs about 48 pounds, sufficient steel being allowed so that the machining process will remove all the outside, weaker stock, leaving only the center, which is not liable to cracks or flaws.

The rough forgings go through two turret lathe operations, one removing the inside stock and the other the outside. The heads and flanges are finished by mill-

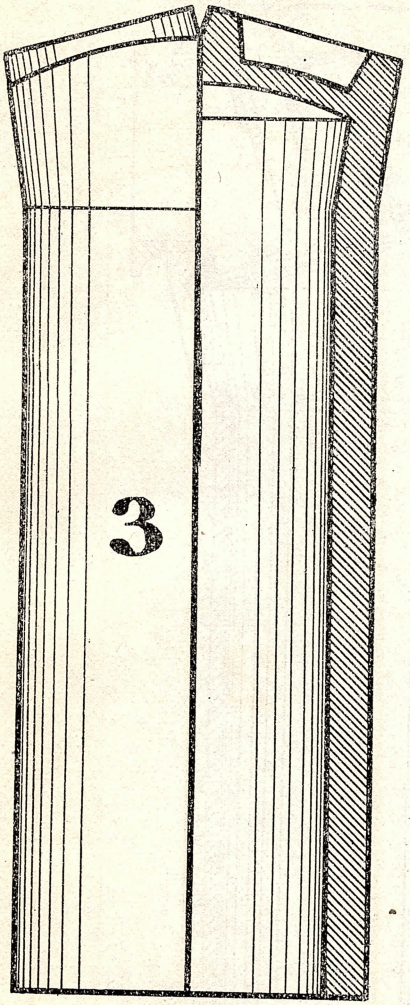



FIG. 2c.

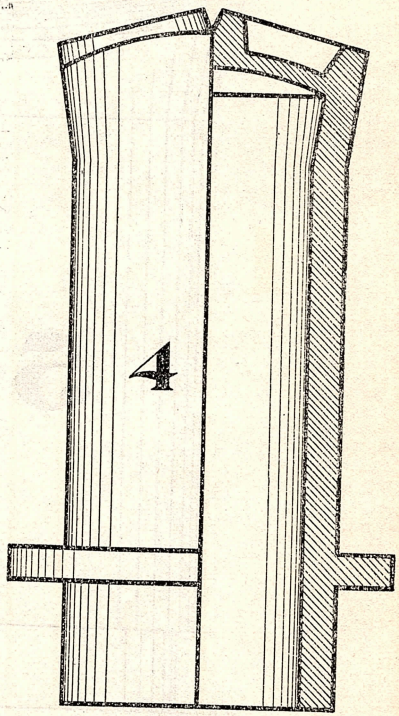



FIG. 2d.

ing and after this is completed, about 40 pounds of steel have been removed from the forging.

The valve elbows are separate steel drop forgings machined to shape, and are electrically welded to the openings in the cylinder heads immediately after they are machined.

The water jackets of 16-gauge pressed sheet steel in two pieces are next welded in place by the oxy-acetylene process, and it is remarkable

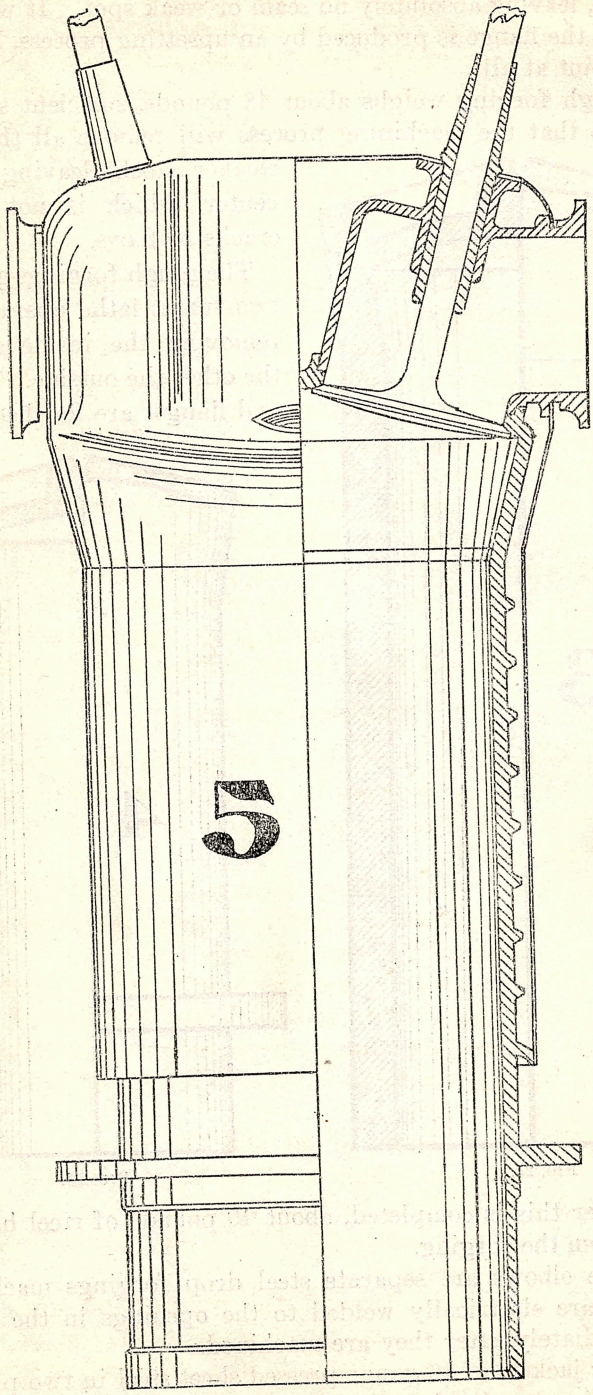



FIG. 2e.

with what skill the work is done. Most of this class of work is done by women, who become very proficient in a short time.

After careful tests of the water jackets, with both water and air, the complete cylinders are subjected to an annealing process, going through enormous furnaces. The heating tempers and toughens the steel, making it of a more uniform texture throughout and eliminating any tendency toward warping which might occur in service.

The inlet and exhaust elbow flanges are then faced off in a milling machine, holes drilled, studs inserted, valve guide holes bored out, and cylinders bored. This latter boring removes only enough stock so that there remains enough for two final grindings to complete the cylinder. Cast-iron valve stem guides are pressed into place, flanges bored, and final inspections and tests made, after which the cylinders are enameled and fitted with valve assemblies.

This type of cylinder, being steel, has a much thinner wall than is required of the cast-iron types, and the water jacket is a great improvement over any possible method of casting, securing a very uniform cooling and having an especially large water space directly around and over the combustion chamber and valve ports.

The flange, being located several inches above the base of the cylinder, tends to hold the cylinder more rigid than the ordinary type, and eliminates any need for the old types of hold-down studs.

### IGNITION SYSTEM.

The Liberty ignition system is the subject of another entire chapter of this manual, so will not be taken up in any detail in this chapter, but it is well to consider it here in connection with other features of the motor.

All other aviation motors which we have known have used magneto ignition, so it appears that some decided advantages were to be gained or this type would not have been adopted.

Undoubtedly one consideration was weight, and it was found that the total weight of this system was much less than that of magnetos.

Reliability was another important consideration, and tests at the time showed this system to be entirely reliable and trustworthy in every possible way.

The uneven firing points of 45 and 75° presented a peculiar problem for the magneto, which could no doubt have been overcome, though possibly at a slight sacrifice of efficiency in the magnetos. This problem was very easily handled in the present system with no complications whatever.

As a whole, it was decided that the expense and work of maintenance and repair of this system was less than that of magnetos, and in actual service it has proven to be a very easy system to keep in operation, under all conditions.

In conclusion, it is only necessary to say that the Liberty ignition system has proven, in actual field service, to be equal or superior to any other type used on aviation motors, and no just criticism can be made of it.

### CARBURETION.

Many types of carburetors were considered, but the Zenith was finally adopted, as it had shown up best on many other aviation motors and gave very good results in all tests made on it. The simplicity of construction and its nonadjustable operation also made it much more desirable than most others.

Of course the intake manifold had to be considered in connection with the carburetor, and the final construction adopted is a very compact and efficient arrangement. The student should examine carefully the construction of these intake manifolds and note the arrangement of baffle plates, which are so situated that the distance traveled by the gas is the same to all cylinders, thereby avoiding any possibility of one cylinder robbing the other. The water jacket over these manifolds is also very well designed, providing just enough heated surface to insure the proper vaporization of the gasoline and air mixture.

As the Zenith duplex type of carburetor has been covered fully in previous chapters, its principles and general construction will not be taken up here, but only such features as differ from the ordinary type will be explained.

The Liberty Zenith was of course designed especially for the motor, with air passages, choke and jets of the proper dimensions to insure most efficient operation. Aside from this, the altitude adjustment was the only new problem to consider, and it was quite important as the motor was to be used mainly at high altitudes.

The drawing shown here should convey the idea of the altitude adjustment clearly to the student's mind, if he is at all familiar with the construction and operation of the Zenith carburetor of the ordinary types.

It will be first noted that the float chamber and compensator well are not open to the atmosphere as in the usual Zenith, but a small tube at (X) admits air to the float chamber. On the Liberty Zenith there are two of these tubes, one at either side, and their openings are so regulated as to allow just enough air to pass through to maintain atmospheric pressure in the float chamber when the throttle is wide open.

Let (L) represent the stopcock in the air passage (P) leading from the float chamber to the carbureting chamber, just above the venturi and below the throttle. When (L) is closed entirely, the Liberty Zenith has no different action from the ordinary Zenith, but

as soon as this stopcock is opened a certain amount of air is drawn from the float chamber, due to the partial vacuum just above the venturi. The air inlet to the float chamber being restricted, this causes a partial vacuum in the float chamber, reducing the flow of gasoline to the main jet, proportional to the amount of air being drawn through passage (P), which is regulated by the stopcock at (L).

The altitude adjustment is not used at all until at an altitude of about 12,500 feet, and above that height it is opened as far as necessary to obtain the best running of the motor. Although the gain in power by use of the altitude adjustment is not appreciable, the

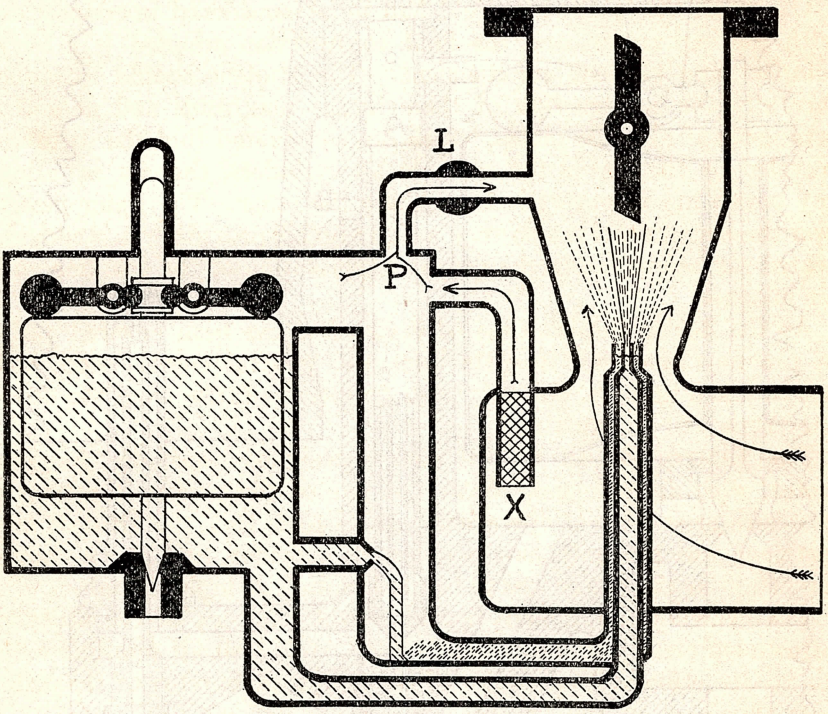



FIG. 3.—The Liberty altitude adjustment.

saving of fuel is worth considering, as well as the fact that the overrich mixture supplied to the motor has no advantage and many disadvantages.

The idea behind this altitude adjustment was very good and it gave good results, though hardly what was expected of it. By closely considering the action of it, one may see that the same action which creates a partial vacuum in the float chamber also creates a like condition in the compensator well. This partial vacuum in the compensator well tends to increase the flow of gasoline through the compensator so that the decrease in flow through the main jet is offset to

a certain extent. For this reason the adjustment has not produced the desired results, though cutting down the gasoline consumption and improving the running of the motor at high altitudes to a great extent.

Various experiments have been conducted in an effort to overcome this slight defect without changing the design of the carburetor, and

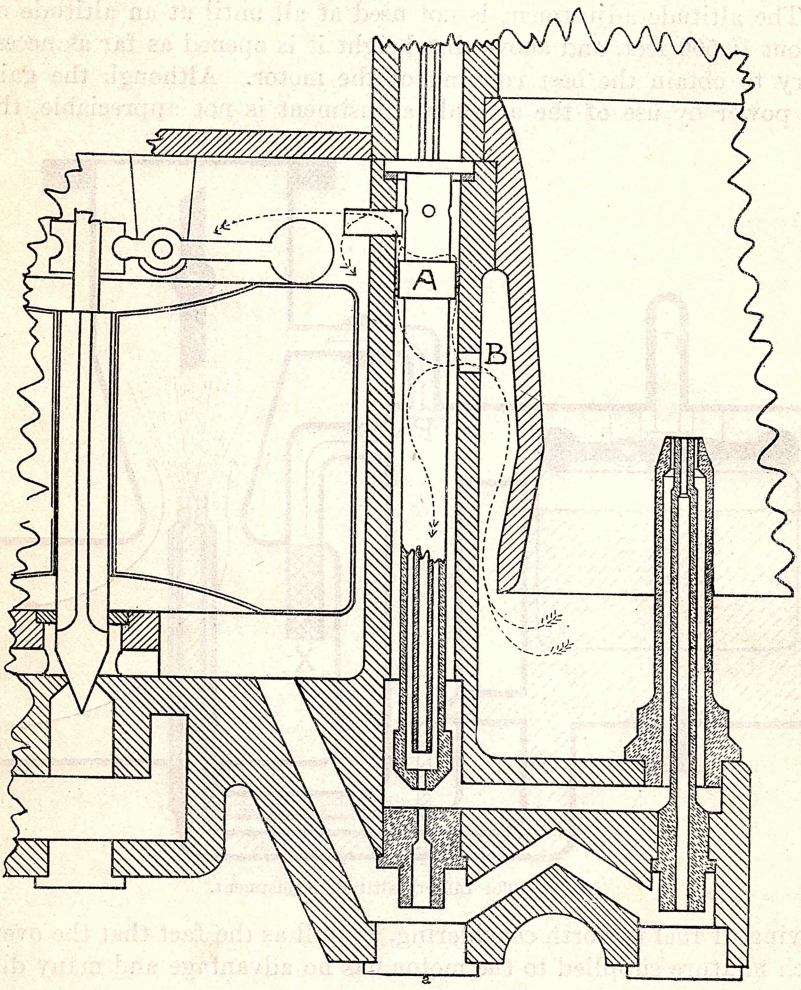



FIG. 4.

a remedy has now been found which produces the required results and may be easily installed either in the factory or by the field mechanics.

To make the necessary changes, the two screened air inlet tubes must first be removed from the carburetor and their openings plugged securely. It will probably be best to thread the holes with

a tap and screw in brass or aluminum plugs, as there must be no air leakage whatever.

The compensator tubes must also be removed and a collar soldered around each, as shown by this sketch. Take careful note of the size and location of this collar, as it is important that it be of this size, which has been determined to give the best results after various experiments. If the collar is too small a sufficient vacuum can not be created in the float chamber, and if it is too large a partial vacuum may be created even when the altitude adjustment is not being used, which would prove very serious.

The Venturi tubes are then removed and a No. 17 hole drilled into each compensator well, as shown in figure 5.

The size of this hole and its location have also been determined by careful experiment, so strict attention should be given to them.

The collars, being of a certain size, regulate the flow of air to the float chamber, and therefore create a partial vacuum when the altitude adjustment is opened, but as the hole through which the air is admitted is below the collar, no vacuum is created

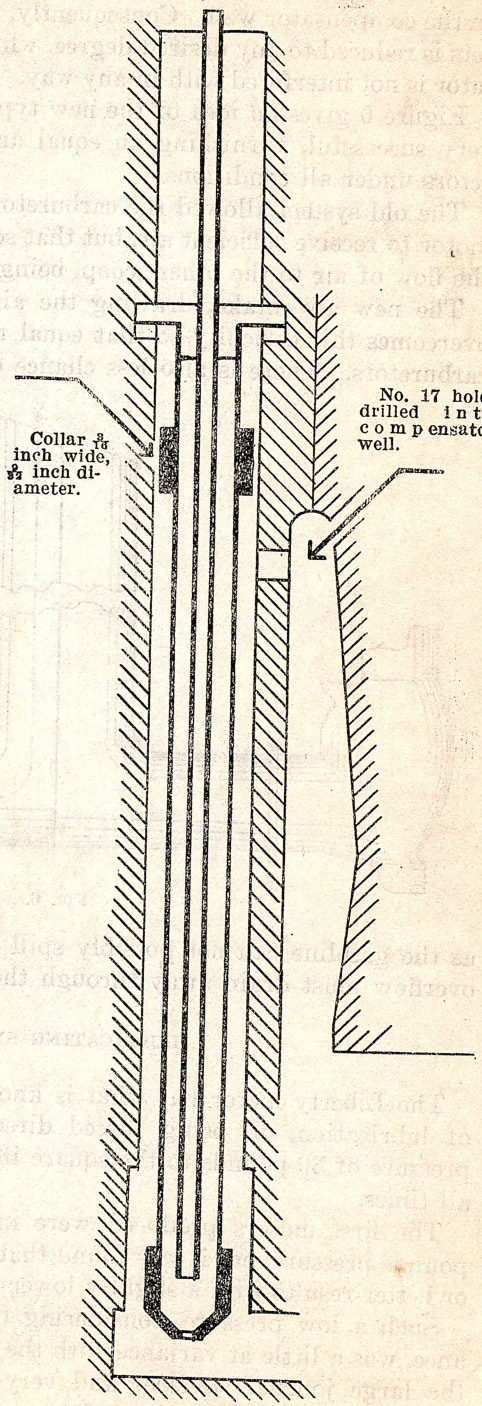



FIG. 5.

in the compensator well. Consequently, the gasoline flow to the main jets is reduced to any desired degree, while the action of the compensator is not interfered with in any way.

Figure 6 gives an idea of the new type air intake that has proved very successful, furnishing an equal amount of air to both carburetors under all conditions.

The old system allowed the carburetor at the propeller end of the motor to receive sufficient air, but that scoop had a tendency to check the flow of air to the other scoop, being directly in front of it.

The new air intake, drawing the air down through a chimney, overcomes this difficulty so that equal results are obtained from all carburetors. There is also less chance of fire with this type intake,

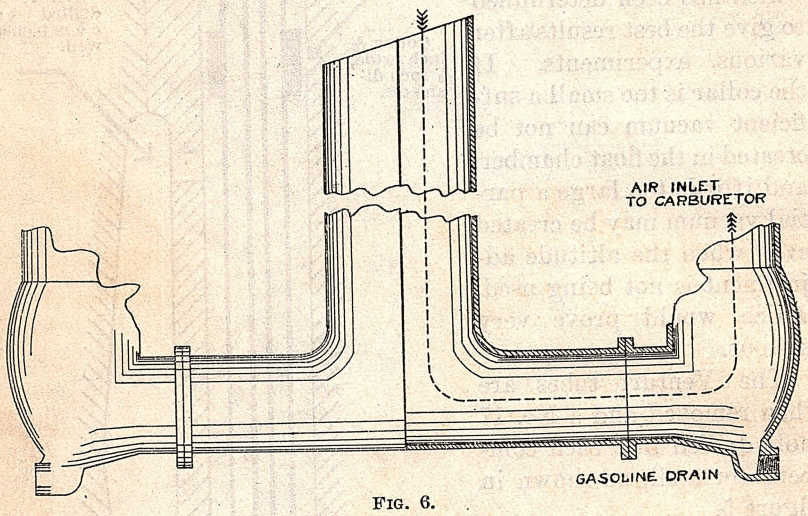



FIG. 6.

as the gasoline can not possibly spill out on to the motor, but any overflow must drain away through the drainage tubes provided.

## LUBRICATING SYSTEM.

The Liberty motor has what is known as a high-pressure system of lubrication, oil being forced directly to the bearings under a pressure of 30 pounds to the square inch, insuring a positive film at all times.

The first motors produced were intended to use from 50 to 60 pounds pressure, but it was found that a lower pressure gave as good or better results with a slightly lower oil consumption.

Such a low pressure, considering the rather large bearing clearance, was a little at variance with the average practice, but owing to the large journal surfaces and very successful oil-cooling system, it has proved entirely successful.

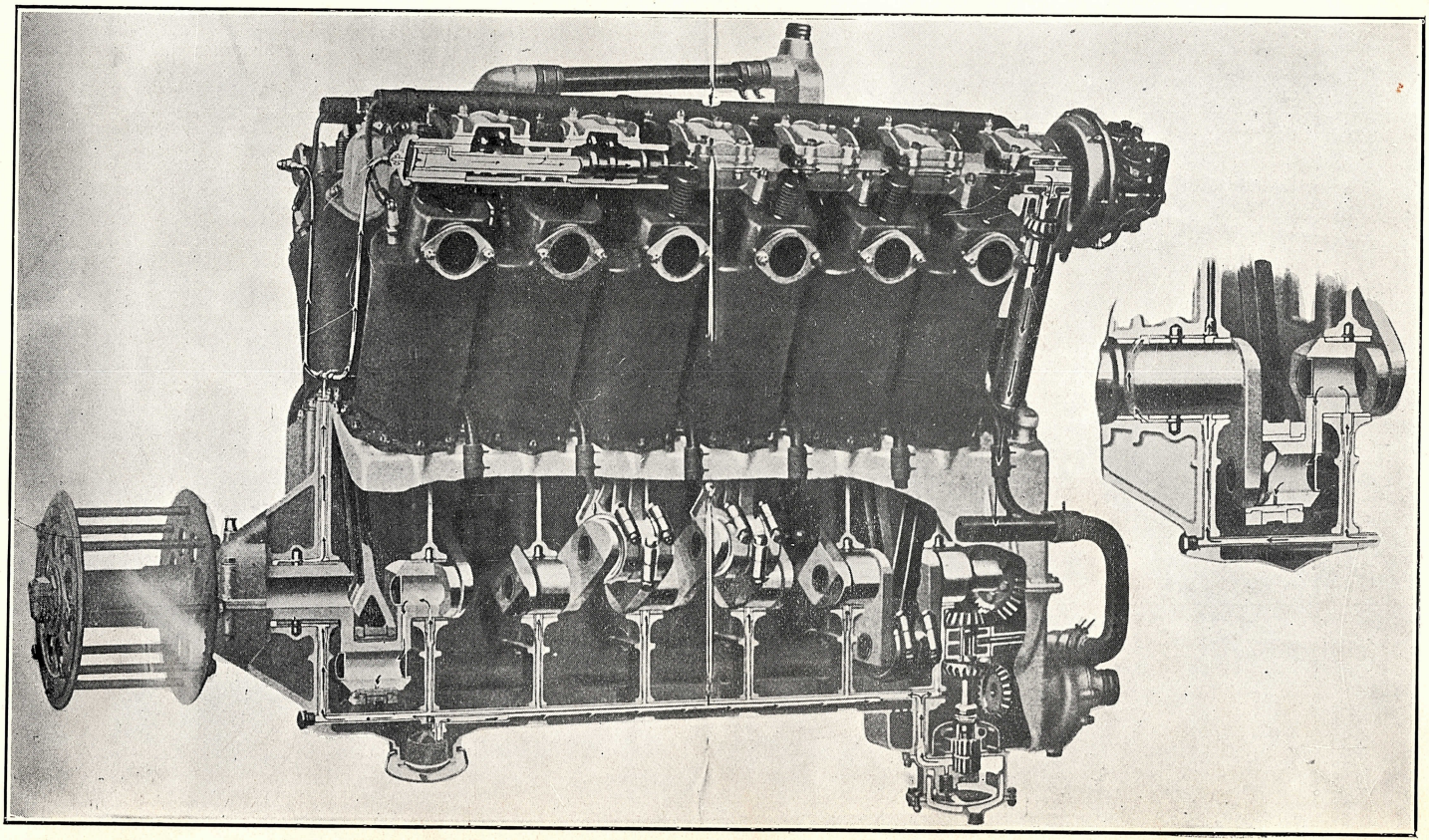


FIG. 7.

Another change that was found necessary to make was in the method of oiling the crank-pin bearings, which were originally oiled from scuppers placed on the crank cheeks, picking up the oil thrown off the main bearings. This method was discarded and the full-pressure feed adopted. By the present system the oil has a positive-pressure feed to the connecting rod big end bearings, which is very necessary, as they are more liable to give trouble than any other parts of the motor.

Starting at the pump we will now trace out in detail the entire oiling system, so that it may be thoroughly understood.

The pump itself is a simple though very ingenious mechanism, and has proved very reliable, but one slight change being found that would improve it, since the original design.

The oil is taken from the base of the pump housing by an ordinary gear pump, consisting of two small spur gears very accurately meshed, and fitted very closely in the aluminum housing. Their action is positive, and being situated in such a position that they are always immersed in oil, there is no possibility of a failure in the operation of the lubricating system.

Located within the pump housing and directly off the oil line leading from the pump is a by-pass valve which controls the oil pressure. This consists of a small valve, so adjusted that it will be lifted from the seat by excessive pressure, allowing a part of the oil which has passed through the pump gears to return directly to the pump base.

As the oil leaves the pump it passes through a pipe leading along the lower part of the crank case, and having branches leading up through the case webs to each of the main bearings.

The crank shaft is hollow, and in each of the main bearings a hole is drilled radially through into the hollow center. As this hole registers exactly with the oil inlet opening in the bearing bushing a small quantity of oil is forced into the hollow shaft at each revolution.

A passage is drilled through the crank web from each hollow main bearing to the nearest crank pin, which is also hollow, and has a radial passage drilled which allows the oil to pass out to the connecting rod big end bearings. The connecting rod bushings are provided with proper oil passages and grooves to insure their proper lubrication.

The oil which has passed through the hollow shaft and escapes around the ends of the bearing bushings is thrown off by centrifugal force, creating an oil mist in the entire crank case, which provides adequate lubrication for the piston pins and cylinder walls. All oil thrown off in this way, and not consumed by passing into the combustion chamber, collects in the two sumps at the bottom of the crank

case, one being directly over the oil pump and the other near the propeller end of the motor.

The upper set of three gears in the oil pump acts as two suction pumps, one drawing off the oil that accumulates in the sump directly over the oil pump and the other drawing the oil through a pipe leading directly from the small sump near the propeller end of the motor. All oil from this double pump is forced out through a passage, marked "Oil out," leading to the reserve oil tank, which acts as a cooling radiator.

The capacity of this double pump is more than twice that of the single pressure feed pump, so that in any position the motor may be placed the sump will be entirely drained at all times.

The reserve tank may be provided to hold any desired amount of oil, and fitted as a radiator which cools the oil, thereby maintaining its viscosity to a greater extent than if it were allowed to accumulate excessive heat.

From the reserve tank a direct passage is provided to the pump base, entering on the opposite side to the outlet, marked "Oil in," so there is no chance of confusing the two connections.

To provide lubrication for the cam shaft, drive shafts and gears, a part of the oil which reaches the main bearing at the propeller end of the motor is carried through a passage around that bearing and up through the crank case to two leads, one to each cam-shaft housing. From the end of the cam-shaft housing the oil is led through a passage in the end cam-shaft bearing to an opening drilled diametrically through it, and registering with a like opening drilled in the hollow cam shaft.

At each revolution, as the openings register, a small quantity of oil is admitted to the hollow cam shaft, passing through it to openings drilled at each of the bearings. The surplus oil gathers in shallow pockets between the bearings, so that the cams dip in oil continually and the splash from them lubricates the rocker arm rollers and bearings.

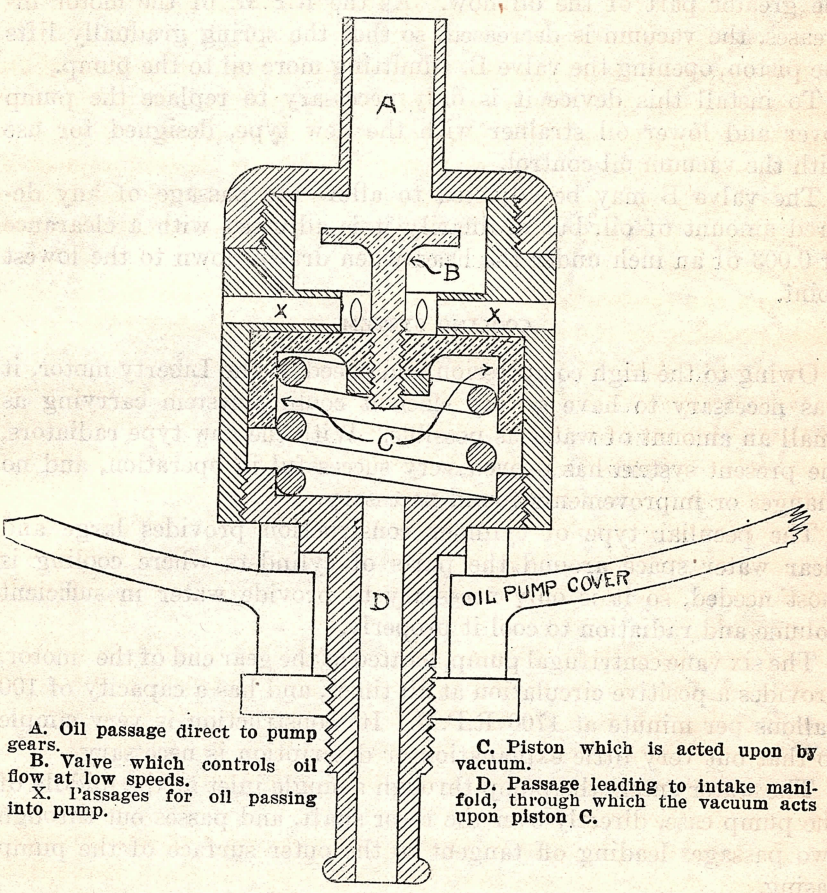
Passages are provided so that the oil gradually passes through to the gear end of the cam shaft housing, over the gears, through the bearings and down through the drive shaft housings to the crank case chamber. In the base of this chamber is an oil trap, which allows the oil to pass through to the main crank case. Several explanations have been given of this chamber and trap, but the most feasible one is that the oil may at times have a tendency to foam, due to the action of the drive shafts and gears. This trap holds back the foam, which would interfere with the action of the pump, but as this foam condenses the oil passes through the trap.

*New pressure control applied to pump.*—The only possible objection that could be made to this lubricating system was the fact that

more oil than necessary was furnished to the bearings at low speeds.

A very ingenious control apparatus has been devised which entirely overcomes this difficulty, and may be installed on the regular pump either in the factory or field shops.

The sketch shown here gives the general plan of this device, with explanations of its parts, so that it may be easily understood.




A. Oil passage direct to pump gears.
B. Valve which controls oil flow at low speeds.
X. Passages for oil passing into pump.
C. Piston which is acted upon by vacuum.
D. Passage leading to intake manifold, through which the vacuum acts upon piston C.

FIG. 8.

It will be seen that its function is to control the inlet of oil to the pump gears, and when the valve is closed or nearly so, but very little oil will be admitted, as oil must pass through this valve before it reaches the gears and is pumped out to the bearings.

It is known that a partial vacuum is created within the intake manifold when a motor is in operation, and it has been determined that this vacuum is greater at low speed than at high, the degree of vacuum created gradually lowering in proportion to motor speed increase.

The operation of this vacuum oil control depends on this fact, its operation being caused entirely by the vacuum under the piston at low motor speeds.

A small tube is connected from the lower end of the control to some convenient point on one of the intake manifolds. When the motor is started the vacuum created in the intake manifold lowers the piston C, which nearly closes the valve B, thereby shutting off the greater part of the oil flow. As the R.P.M. of the motor increases, the vacuum is decreased, so that the spring gradually lifts the piston, opening the valve B, admitting more oil to the pump.

To install this device it is only necessary to replace the pump cover and lower oil strainer with the new type, designed for use with the vacuum oil control.

The valve B may be adjusted to allow the passage of any desired amount of oil, but ordinarily it is adjusted with a clearance of 0.003 of an inch under the head when drawn down to the lowest point.

## COOLING SYSTEM.

Owing to the high compression and speed of the Liberty motor, it was necessary to have a very efficient cooling system carrying as small an amount of water as possible. With the new type radiators, the present system has proved very successful in operation, and no changes or improvements found necessary.

The peculiar type of cylinder construction provides large and clear water space around the parts of cylinders where cooling is most needed, so it is only necessary to provide water in sufficient volume and radiation to cool it properly.

The six vane centrifugal pump, located at the gear end of the motor, provides a positive circulation at all times, and has a capacity of 100 gallons per minute at 1700 R.P.M. Its construction is very simple so that but very little explanation or description is necessary.

The water enters the pump through a single inlet at the middle of the pump case, directly over the rotor shaft, and passes out through two passages leading off tangent to the outer surface of the pump casing.

Each of these feeds a header leading to one cylinder bank, having branch outlets to each cylinder water jacket. The return water is taken from a long tube leading from the lower part of the radiator.

A very ingenious method of maintaining the pump packing compression is provided, a coil spring pressing equally on two bronze glands, so that any wear of the packing is automatically taken care of.

It will be noted that the construction of the Liberty pump is slightly different from most others, but its action is exactly the same as all other centrifugal pumps.

It will also be noted that the design of Liberty cylinder water jackets, inlet and outlet headers, insures a very uniform cooling at all points and does not require an excessive quantity of water, the entire cooling system from inlet to outlet header holding but 5½ gallons.

OVERHEAD CAM SHAFT.

The arrangement of the valve operating mechanism of the Liberty is in accordance with the very best practice and is an improvement over most of the other aviation motors we know.

No feature of the entire assembly has shown any weakness, and but one change has been necessary since the original design, that being merely a slight change in the method of lubrication of the rocker arm bearings.

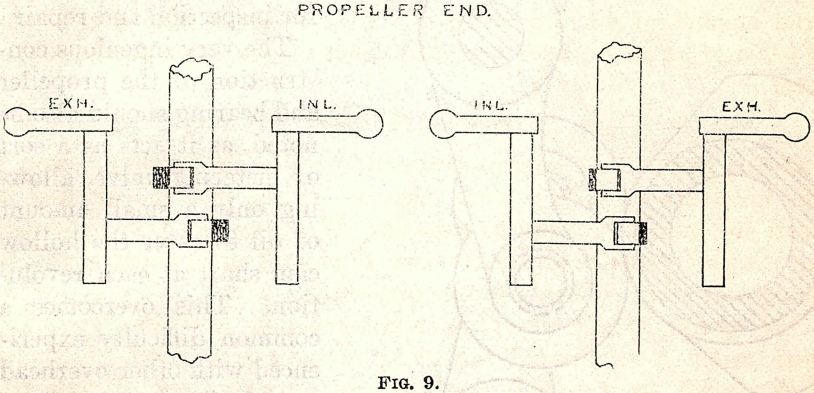



FIG. 9.

The cam-shaft housings are both exactly alike, but it will be found that there is a great difference between the two shafts, so that it is necessary to always make sure that right and left cam shafts are properly located.

The right-hand cam shaft has the exhaust lobes (the wider ones) toward the propeller end of the motor, while the left-hand cam shaft has the intake lobes (the narrow ones) toward the propeller end. It will also be seen that the angles between the lobes are different, as shown by sketch, this being necessary, not because of the 45° cylinder angle, as some assume, but entirely owing to the fact that the rocker-arm rollers are not centered over the cam shaft. For this reason, we may say that the intake lobe on the left side strikes the rocker early, while the exhaust lobe on the left strikes its roller late, and just the opposite condition exists on the right-hand cam shaft, making it necessary to have different angles between the lobes of the two cam shafts.

The sketches shown here should convey this idea clearly, as it is rather difficult to explain to the student unless the motor is at hand or sketches can be had which show the action very clearly.

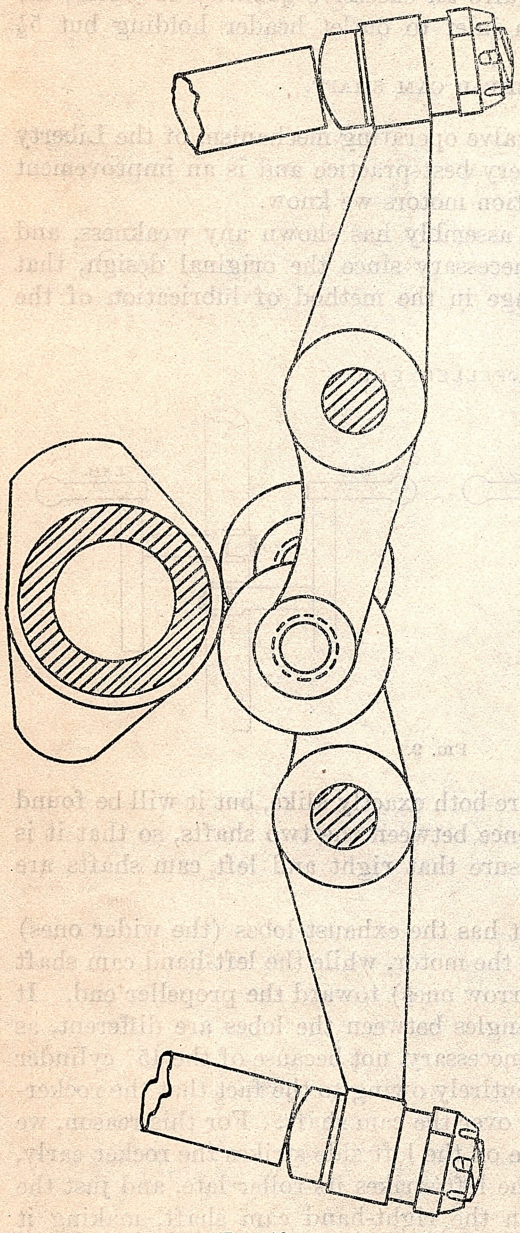


FIG. 10.

One small feature of construction of the cam-shaft housing and bearings is worthy of special note, that being the step up in size of each bearing one sixty-fourth of an inch, so that the cam shaft may be easily drawn out for inspection and repair.

The very ingenious construction of the propeller and bearing should also be noted, as it acts as a sort of metering valve, allowing only a small amount of oil to enter the hollow cam shaft at each revolution. This overcomes a common difficulty experienced with other overhead cam-shaft motors, of excessive oil, which is thrown off by the rocker-arm action. This difficulty is almost entirely overcome in the Liberty, the cam-shaft bearings and rocker arms being well lubricated, but practically no oil being thrown off by their action.

The construction of the cam-shaft drive shafts is such that they have proven to be very reliable, free from noise and vibration, and in every way all that could be desired. Some advocate chain drive, others a chain of gears, but evidently the bevel-gear drive shaft as used on the Liberty

has every advantage over either system, for it is a positive action, with few parts to wear, break, or get out of adjustment, and is also very light weight.

It is well to mention again what has already been said in a previous chapter in regard to valve timing, as it is very important that the valve clearance adjustment be thoroughly understood. In timing Liberty valves a uniform clearance must not be followed, but a regular timing disk must be used, and the clearance of each and every valve adjusted to bring the action as near as possible to correct, by degrees of crank travel.

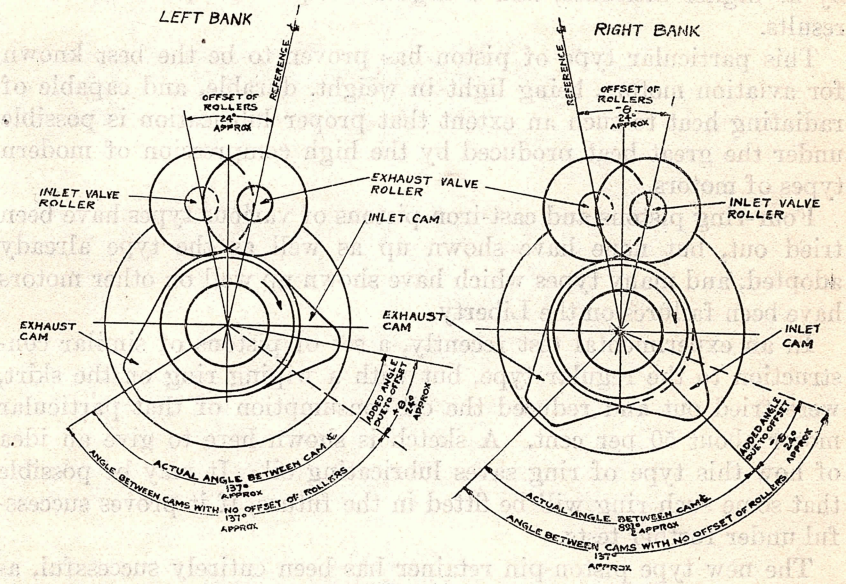

LEFT BANK
REFERENCE
OFFSET OF ROLLERS 24° APPROX
INLET VALVE ROLLER
EXHAUST VALVE ROLLER
INLET CAM
EXHAUST CAM
EXHAUST CAM
ADDED ANGLE DUE TO OFFSET 24° APPROX
ACTUAL ANGLE BETWEEN CAMS 137° APPROX
ANGLE BETWEEN CAMS WITH NO OFFSET OF ROLLERS 131° APPROX
RIGHT BANK
REFERENCE
OFFSET OF ROLLERS 24° APPROX
INLET VALVE ROLLER
INLET CAM
ADDED ANGLE DUE TO OFFSET 24° APPROX
ACTUAL ANGLE BETWEEN CAMS 89½° APPROX
ANGLE BETWEEN CAMS WITH NO OFFSET OF ROLLERS 137° APPROX

FIG. 11.

## CONNECTING RODS.

The forked rod construction of the Liberty is not new in any way, having been tried out successfully on one of the better types of automobiles, but many thought it would not stand up under the great pressure put upon it by the Liberty. It has proven entirely successful, however, though as usual in all gas engines, the connecting rod bearings show signs of weakness before the other bearings of the motor.

The first rods used proved to be too light weight, so the design was changed to strengthen them slightly, and larger, or rather heavier, big end bushings were used. Since then no trouble has developed and no further changes have been made.

This type of rod construction makes it possible to use a shorter crank shaft than with the side by side construction, eliminating unnecessary weight in both shaft and crank-case construction.

### PISTONS.

The Liberty is fitted with one of two standard types of pistons, known as Army and Navy types, both being three-ring pistons, of aluminum alloy; the only difference being that the Army type is higher compression than the Navy type. This is necessary owing to the fact that the Army type is used in planes which generally fly at higher altitudes, and a higher compression produces better results.

This particular type of piston has proven to be the best known for aviation motors, being light in weight, durable, and capable of radiating heat to such an extent that proper lubrication is possible under the great heat produced by the high compression of modern types of motors.

Four-ring pistons and cast-iron pistons of various types have been tried out, but none have shown up as well as the type already adopted, and many types which have shown up well on other motors have been failures on the Liberty.

In an experimental test recently, a set of pistons of similar construction to the regular type, but with a wiping ring on the skirt, were tried out and reduced the oil consumption of that particular motor about 50 per cent. A sketch is shown here to give an idea of how this type of ring saves lubricating oil. It may be possible that some such ring will be fitted in the future, if it proves successful under further tests.

The new type piston-pin retainer has been entirely successful, as with the floating type pin, it acts as a bearing for the pin ends so that in no possible way can any injury be done to the cylinder walls.

It is very easy to insert or remove these retainers, it only being necessary when placing them to use a straight edge along the sides of the piston, making sure that the surface of the retainer does not extend above the surface of the piston.

### CRANK SHAFT.

The Liberty crank shaft is truly a wonderful piece of forging, and considering it shape, length, and the great stresses placed upon it, we can say that the designer used very good judgment, for it has stood up under some very severe tests, as well as actual service.

The later type shafts, for a greater factor of safety, have been made slightly heavier than the original design, the webs being

broader, and none have been known to fail under ordinary conditions.

One of the old type shafts was used in a motor for experimental purposes, and was subjected to unusually great strains. This motor developed 525 horsepower, at a speed of 2,175 revolutions per minute and was run at speeds as high as 2,300 revolutions per minute.

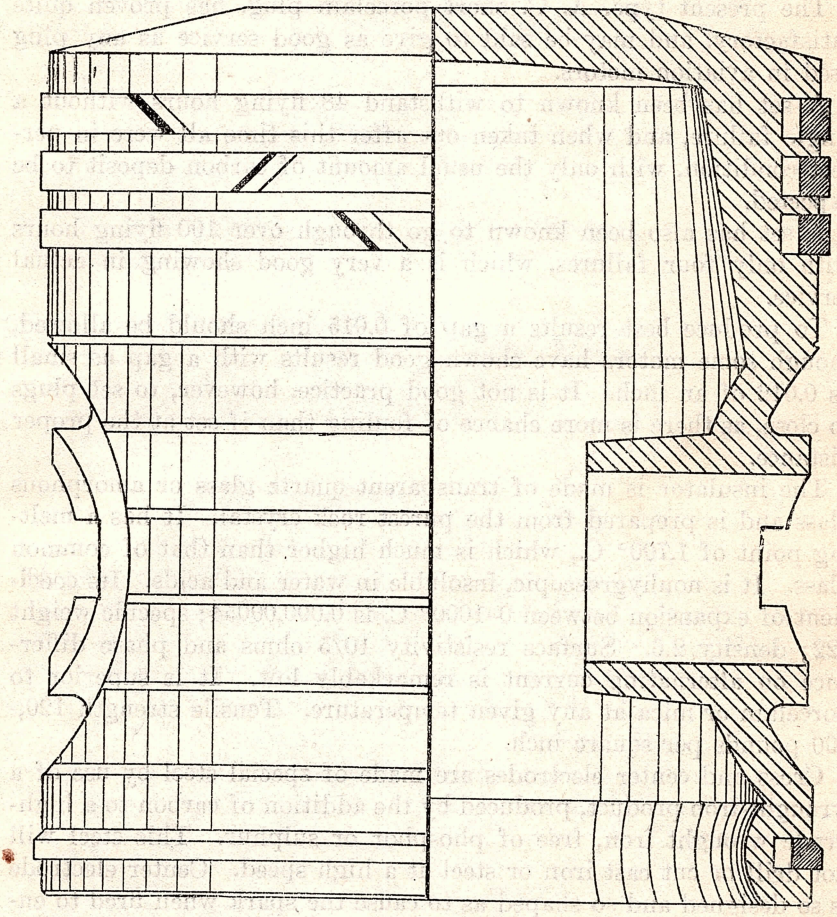


FIG. 12.

This was a very severe test for the light weight shaft, and, though it showed no weakness during this run, it fractured on a later run at ordinary horsepower, so it was assumed that the first run probably caused some damage which was not to be seen at the time. It is believed that the new type shaft would have withstood this test, which is far greater than the ordinary running conditions would ever demand.

## SPARK PLUGS.

There has been some difficulty in procuring a spark plug which would stand the high compression of the Liberty motor. The trouble has been partly due to the pockets in which the plugs are located, which have a tendency to cause heating, as the air circulation through these pockets is not as good as it should be for perfect cooling.

The present type, A. C. short porcelain plug, has proven quite satisfactory, and may be said to give as good service as any plug used in aviation motors.

A set has been known to withstand 48 flying hours without a single failure, and when taken out after this time all were in perfect condition, with only the usual amount of carbon deposit to be expected.

A set has also been known to go through over 100 flying hours with only four failures, which is a very good showing in actual service.

To produce best results a gap of 0.015 inch should be allowed, though some motors have shown good results with a gap as small as 0.012 of an inch. It is not good practice, however, to set plugs so close, as there is more chance of fouling than if set at the proper distance.

The insulator is made of transparent quartz glass or amorphous glass and is prepared from the purest rock crystal. It has a melting point of 1,700° C., which is much higher than that of common glass. It is nonhygroscopic, insoluble in water and acids. Its coefficient of expansion between 0–1000° C. is 0,000,00054; specific weight 222; density 2.6. Surface resistivity 10/5 ohms and phase difference on alternating current is remarkably low. It is superior to porcelain or mica at any given temperature. Tensile strength 120,000 pounds per square inch.

Cross and center electrodes are made of special steel by use of a wrought-iron product, produced by the addition of carbon to a high-grade wrought iron, free of phosphor or sulphur. This steel will not drill or cut cast iron or steel at a high speed. Center electrode is so designed and so shaped as to cause the spark when fired to encircle cross electrode, spreading at the same time; the spark thus sprays itself against compression, giving in turn a quicker start of combustion. The center electrode is cast and moulded in a composition of bakelite and mica; same is formed by use of hydraulic pressure and under extreme heat conditions; will not fuse or become elastic under 1,500° C. heat and is an absolute electrical insulator.

This plug was tested for gas tightness with compressed air at a pressure of 225 pounds per square inch while the plug was im-

mersed in a bath of oil heated to 150° C. This served to duplicate the condition in the engine which might have caused leaks due to the thermal expansion of the various parts.

The cold dielectric strength test was made by applying a 60-cycle voltage from a transformer to the plug insulator while immersed in a vessel of oil. The voltage was raised gradually to 25,000 volts and no puncture of the insulating material was noticeable. Engine tests consisted of running the plugs in a 12-cylinder Liberty motor at full load for a period of 3 hours and light load for 1 hour; general performance of plugs very good.

## Chapter III.

# PROPER DISASSEMBLY AND INSPECTION OF LIBERTY MOTOR.

### USE OF TOOLS AND METHODS OF WORKING.

Presuming the student of mechanics to be unfamiliar with all details of this motor, each step will be taken up carefully as we come to it, and the endeavor made to explain all the details in a way that they may be easily understood by the student, with no chance of a misunderstanding or room for argument on any point. In order to do the work properly, the student should be supplied with sufficient tools of the proper kind, and care taken by the instructor to see that he handles all tools properly. For instance, special socket wrenches are furnished for certain nuts, and should be used in their proper places. A crescent wrench should be used only when no suitable end or socket wrench is available, and then care must be taken that it be kept adjusted snugly to the nut, for otherwise many nuts will be ruined. Pliers must never be used on nuts or studs or in any way that may be likely to injure any part of the motor. For removing cotters, a medium-sized pair of diagonal cutters will be found most convenient, and the work may be done quite rapidly by using them properly. If possible, gear pullers should be at hand for removing cam-shaft gear and drawing off water-pump impeller. In pulling the cam-shaft gear, do not put unnecessary strain on puller, but tighten up gradually, tapping lightly at different points on the gear as puller screw is turned. A timing disk and pointers should be in every tool kit and students should be taught how to use it. Battery and light should be used, if possible, for synchronizing breakers, as they prove to be a most convenient and accurate method.

Many mechanics disassemble a motor completely, neglecting to take note of wear, defects, clearances, timing, or replacements necessary to be made, and then find that they are caused much unnecessary trouble and waste of time in reassembling. Every part should be examined carefully as motor is disassembled, wear or breakage noted, timing of motor checked, condition of bearings, valves, gears, pistons, ignition system, and carburetors given special attention, and a record made of all repairs and adjustments that

will be required. This is a point on which the majority of mechanics have a tendency to be lax, so instructors must impress it firmly on the students' minds and insist that it be carried out.

### REMOVE SPARK PLUGS.

The reason for this will be apparent to the student, as it takes considerable effort to turn the crank shaft against compression. After removing plugs there is always a possibility of dropping cotters, nuts, or other objects in the cylinders, which may injure cylinder walls or pistons; so it is best to provide some means of closing spark plug holes without creating compression. Wooden plugs of the proper size with an eighth-inch hole bored through them serve very well, or old spark plugs may be used, simply removing the porcelains and filling with lead or babbitt, boring an eighth-inch hole to relieve compression. Another method is to solder a small piece of screen over hole through plug.

### CHECK TIMING AND TAPPET CLEARANCES.

Before checking timing take notice of the way in which cylinders are numbered on the Liberty motor. Right and left banks are numbered separately from 1 to 6, beginning at the gear end, and right or left is determined by facing the gear end of the motor. The plate which is placed on gear end of crank case, showing firing order, does not show cylinder numbering, but only the consecutive order of firing of the cylinders. Do not become confused on this point, as it is important that you know it correctly. The direction of rotation should be determined in the usual way, as taught in elementary classes, and will be found to be clockwise. Just as a reminder, it is well to keep in mind that we now determine this point from the gear end of the motor, facing the motor and comparing its rotation to the hands of a clock, from which we get the terms "clockwise" or "anticlockwise."

*Locate top dead center (T. D. C.) No. 6 left cylinder.*—The usual method of locating this point by timing rod should already be familiar to students, so needs no discussion. Put timing disk on the hub, placing the odd hole over dowel pin in flange, and put two or three short bolts with washers in place to hold it loosely. Place pointers on front cylinder studs and shift either disk or pointers lightly until left pointer is exactly in line with point on disk marked T. D. C. 1–6. Tighten nuts now so that neither disk nor pointers can shift, then turn crank shaft 45° in direction of rotation, locating top dead center on the right bank in the same manner as on the left. As the two points are not always correctly spaced, do not depend on them, but use the same care in locating T. D. C. on the right as on the left. If right pointer does not coincide exactly with the same point

on the disk, as the left did, bend it until it assumes correct position. To test the accuracy of your work, it is well to measure off a distance on the timing disk, equaling 45°, and determining if this is the exact distance between the two points. If it is not, you have made a mistake somewhere, and should go over the work again with more care. Now proceed to check carefully the timing of two or three cylinders at least, finding the exact degree of valve opening and closing, both intake and exhaust, and noting the clearances of tappets on these same cylinders. In checking valve timing the student must become accustomed to the feel of rocker arms, so that he can determine exactly when the tappet comes in contact with the valve stem, which is the point of valve opening. He must also be able to determine just when the tappet is leaving the valve stem, which is the point of valve closing.

Some mechanics attempt to use thin paper or thin stock in determining valve openings and closings, but that is not an accurate method and is also very slow. Accustom yourself to the feel of the rocker arms, which will prove to be the only satisfactory method. Clearance of intake valves should average 0.014 to 0.016 inch; clearance of exhaust valves should average 0.019 to 0.021 inch. Owing to slight inaccuracy of grinding cam lobes, etc., it is usually necessary to alter these clearances in order to get correct timing, and in exceptional cases, it may be necessary to bring the intake clearance as low as 0.010 inch and the exhaust as low as 0.015 inch. Under no circumstances should the clearances be less than these figures. If it becomes necessary to increase the clearance to more than the maximum stated above, no harm will be caused, provided the increase is not more than about 0.005 inch. Too great a clearance would decrease the valve opening, which might prove very serious. The exact degrees of valve opening and closing should be as shown on the diagram. (See fig. 19.) This does not in any way represent the timing disk, as valve action of only one cylinder is shown. It will be noticed that there are three top dead centers 120° apart, shown on the timing disk, as well as three each of all other valve openings and closings, in their proper positions. These three points correspond to the angles at which the crank throws are set, and you will find that two cylinders, 1–6, 2–5, 3–4, are always on top dead center at the same time, these pairs of cylinders being so located that their connecting rods are on crank throws of the same position. However, it will be understood that when No. 1, for example, is at top dead center on the power stroke, No. 6 will be at top dead center at the end of exhaust stroke, the same applying to all pairs on both banks. It will be noticed on diagram No. 1 that the ignition system is set to fire at 30° before top center, at full advance. In checking the motor, you should also check the breaker openings, determining

whether or not the spark was properly timed, and whether or not the two ignition heads were synchronized. To many students it will seem unnecessary and a waste of time to go into so much detail in checking over the timing, clearances, etc., as has been mentioned, but on second thought it should be apparent to all that these things are essential to a thorough understanding of the motor; and it is to the advantage of every student mechanic to familiarize himself with every possible detail of the motor on which he is working.

### EXAMINE AND REMOVE IGNITION SYSTEM.

For several reasons, it is best to remove all high tension cables from distributor cover terminals, although many do not do so. First, it is necessary to give all cables a thorough examination to make certain that no strands are broken from kinking, or the rubber covering has not worn through from contact with some part of the motor or fuselage. A point which quite often breaks, and may be nearly broken off before being noticed, is at the terminal loop, about half an inch inside the rubber covering. A small copper tube covers the end of the wire, forming the loop and extending underneath the rubber covering. Several strands of wire may be broken at the inner end of this tubing and still be unnoticed. Though the newer type motors have extra heavy rubber tubes to reinforce these points each cable should be inspected carefully. Next remove screws which hold cable tube clips, and lift off cable tube. The cable tube should be hung on a convenient peg or hook, if possible, to avoid injury. Remove and examine distributor covers, taking notice especially of contact segments and path of rotor brush, which should be smooth and free from cuts or grooves. Some carbon will naturally have accumulated and should be wiped out with a cloth dampened with gasoline. The coils are built into the distributor covers and sealed over with a fiber plate. All connections are made inside the cover, and there should be no reason for removing either the plate or coils. Never do so, unless in an emergency, where coil or inside connection is known to be burned out or broken, and no spare distributor covers are available. This sort of work should be done only by a man with considerable experience in ignition work. See that there is but slight free movement of the rotor arms. If more than about one-sixteenth inch it will denote excessive wear between the driving flange and driver. Disconnect the cross reach rod between two distributor-control arms and remove distributors by taking out six bolts through flange of each. Check the gap of each breaker with breaker block on wide lobe of cam. The clearance should be from 0.010 to 0.013 inch on each of the three.

At this time the general condition of the entire assembly should be checked up to determine if any replacements are needed. If any parts are worn or damaged, they should be replaced and fitted now; or if the spare parts are not in stock, they should be ordered at once so they will be on hand when motor assembly is completed. Contact points should not be pitted, and if so, they should be smoothed on a stone, as it is impossible to file them. Rubber buffers at ends of breaker arm springs should be in good condition, neither stiff or dead as rubber becomes with age, or soft and spongy from oil soaking. Breaker arm springs should show no signs of weakness or cracking at holes. If possible, test these springs for tension, the proper amount being 16 to 20 ounces for auxiliary breaker spring, and 28 to 30 ounces for main springs, when contact is open. The face of the cam should not show excessive wear, and should be bright and smooth. Fiber blocks which bear against should not be worn down and should show clean, smooth wearing surface. The resistance unit, wound on a porcelain spool at base of auxiliary breaker arm spring, must be in perfect condition. If coils are meshed together in any way, the unit will not furnish sufficient resistance, so the coils should be very closely examined. It is well to take notice of the construction of this spool, as it may be placed in only one way, and if accidentally put in backwards it will form a short circuit instead of resistance, which might prove very dangerous to the man starting the motor. The carbon brush at end of rotor arm should be not less than one-fourth inch long, clear of the end of spring. In placing a new brush, carefully push it down with small punch as far as possible, to properly seat spring. It is very important that the ball bearings which carry distributor shaft be in good condition. They should show but very slight radial or lateral clearance and should turn entirely free in all positions. If there is any doubt about the condition of these bearings, they should be removed and examined carefully. By removing screw at inner end of rotor arm, it is easily removed so that shaft may be driven out through the cam. Use a small punch for doing this, which will not strike the key in cam. Before reassembling, pack the bearings with clean vaseline and saturate felt filler inside each cam with some good light oil. Be very careful in replacing cam that it is not twisted or sprung in any way, and keyways line up perfectly true.

### DISMOUNTING GENERATOR.

It will be found most convenient to dismount the generator next, and by so doing the entire ignition system has been cared for at one time. Remove nuts and washers from three flange hold down studs and generator may be lifted off easily. The first detail to take note

of should be the condition of splines at lower end of shaft. Any excessive wear may be easily detected, and such will only occur when there is some serious defect in the fit or mesh of the splines. The tachometer assembly, at base of generator, should be removed and condition of worm gear and bearing bushings noted. The worm gear, shaft, or bushings should not show excessive wear, roughness, or scores. Before replacing the shaft in bearings, the space between bushings and the teeth of the gears should be filled with vaseline. The cap over upper end of generator is easily removed by taking off two terminal nuts and lifting carefully. Condition of both commutator and brushes may be examined easily with cover removed. If the commutator is smooth, showing a bluish color, with no signs of scoring or burning, undoubtedly the generator has been functioning properly and needs no repairs. The bearing at upper end of generator shaft is lubricated by a few drops of oil at the end of each long flight, or about every five running hours, and should be perfectly free, but not show any appreciable wear, which would allow slight radial movement.

### DISASSEMBLING AND REPLACING WORN PARTS.

In case it is necessary to disassemble the generator, it should be very carefully done, so that no parts will become injured or destroyed. First remove nuts from terminal which is marked "Gen. field" on the cap. This may be easily distinguished, as it is the smaller of the two terminals. Also remove nut from bolt which extends through the brass bus bar at about its center, and the nut from end of generator shaft. Next remove lock wire which passes through the heads of four long frame bolts and screw out the bolts. This will allow the base, fields, armature, and bearing assembly to be separated. Carefully press down on terminal bolts from which nuts were removed, as top of generator is lifted off, as these two bolts are connections of the field windings, and, if care is not taken, one or both cables may be broken off. Repairs to commutator, armature, or brushes should not be made unless mechanic is familiar with this kind of work, and competent to do it correctly; so students should be cautioned not to attempt repairs unless they have been instructed as to proper methods. Occasionally it may be necessary to polish a commutator, replace broken brushes, or other minor repairs, which may be done by the average mechanic, with proper care. Any deep scratches or grooves on the commutator should be removed only by turning down in a lathe, and should not be attempted in any other way. New brushes, or old ones, which do not have proper contact with the commutator, should be sanded so as to give them a perfect bearing at all points. This is done by

placing a strip of very fine sandpaper, not emery, around commutator under the brush, and rocking armature back and forth until proper surface is obtained.

### REMOVE CARBURETORS.

As instructions and lectures have already been given the student on Zenith carburetors, he should be familiar with its general details and principles. In a few minor details the Liberty Zenith differs from the ordinary type, and, if student is not already positive of his understanding of these details, he should take up the study of them at once. Disconnect and remove altitude adjustment rod as well as throttle control rod, before loosening carburetors, as otherwise they are likely to be twisted or bent out of shape. Four bolts, extending down through the water outlet headers, must be removed in order to allow carburetors to drop down where they may be taken from the motor. As three of these bolts are situated in such a way that they can not be taken entirely out, it is necessary to turn them with an end wrench, releasing both evenly, so there is no possibility of stripping threads or injuring the joints between carburetor and manifolds. Gaskets should be examined, and placed in some place where they will not be broken or meshed, as an air leak may easily cause much trouble if poor gaskets are used.

### REMOVE WATER OUTLET HEADERS.

Water outlet headers, hose, and extension tube may all be removed as one assembly, and need not be separated unless hose needs replacement. Remove nuts from four studs of each header and lift the entire assembly off. Lay gaskets aside where they will not be damaged. Examine hose connections and clamps to make sure they are in good condition.

### REMOVE INTAKE MANIFOLDS.

The new type manifolds are much more easily removed than the old, having the holes in flanges slotted so that manifold may be lifted off, without effort, when nuts have been loosened a few turns. First disconnect the water inlet elbows by removing two cap screws from each one, leaving elbows and hose connections attached to cylinders. Next remove nuts, or loosen a few turns, lift manifolds off one at a time. Examine all gaskets to see that they are not damaged, and that openings line up properly. It is best not to leave the gaskets on cylinder studs as they are likely to become damaged from handling cylinders.

### REMOVE CAM SHAFT HOUSING UNITS.

It is well to consider here a few details of these units which must not be overlooked. The two assemblies appear to be exactly alike, and are so in every way, excepting the cam shafts, which are made right and left, not being interchangeable. As the joints between covers and housing are lapped, and drilled to fit in only one place, all caps are numbered to correspond with numbers on the housing and must not be placed elsewhere. It is also important that these parts be handled carefully to avoid roughing the contact surfaces, which must form an oil-tight fit. Disconnect and remove cam shaft oil leads, at propeller end of motor, before removing any part of cam shaft housing units. Unscrew the packing nut at lower end of vertical drive shaft housing with the special spanner wrench provided for that purpose. Do not remove drive shaft housing from cam shaft housing at this time, as it is more convenient to handle them together. Remove the 12 nuts and washers from cylinder studs, and lift entire unit from the motor, raising both ends evenly to avoid bending the cylinder studs. It is best to replace all washers and nuts on their proper studs, or if not convenient to do this always, place all nuts and washers from one unit or of one size and class on a wire, or in some receptacle, separate from those of other parts of the motor. Give entire assembly a careful inspection at this time, noting condition and clearances of bearings, lash of gears, wear of tappets, and condition of cam surfaces. As they are taken off, examine rocker arm bearings and lay them in their proper covers so they will not become misplaced. They should have 0.005 to 0.010 inch end play and 0.001 to 0.0015 diametrical clearance in bearings, which will be a free fit, but not loose enough so that a shake can be noticed. The tappets should be examined for wear, as now and then one might get by the inspectors which has not been properly heat treated, and in such a case would be too soft or too hard, causing uneven wear. Examine the rollers for cracks, flat spots or undue bearing wear. The end play in the fork of the arm should be 0.010 inch and the diametrical clearance 0.001 inch.

### REMOVAL OF CAM SHAFT.

After covers and rocker arms are removed, it will only be necessary to take out the seven cam-shaft bearing lock screws, after which cam shaft and bearings may be easily drawn out from the gear end. Bearings from one section of cam shaft are not interchangeable to another section. Inside measurements are the same, but outside diameters are stepped down from gear end to propeller end, each bearing being one-thirty-second inch smaller than the one next to it. This feature makes the removal of cam shaft very easy. The

front bearing, which did not come out with the shaft, may be removed by taking off the cam-shaft housing front cover and pushing from the rear. Usually, it will be found loose enough so that by grasping the head of one of the cover screws, it may be pulled out with a pair of pliers. All bearings should be so fitted in the housing that they may be removed freely, but not loosely. Examine the cam-shaft bearings for clearance and general condition. The bearing surfaces should be smooth and clean. There should be a diametrical clearance of about 0.0015 inch on the shaft, with end play on gear bearing between flanges of about 0.002 inch. Examine cam shaft, seeing that all bearing surfaces are smooth, and cam faces show no signs of soft spots, cracks or scratches. Before removing the upper drive shaft, examine the gears, seeing that no teeth are damaged or show excessive wear. The gear lash should be at least 0.005 inch and not over 0.010 inch and the drive shaft should have about 0.008 inch end play. Remove upper drive shaft by taking off the four nuts from studs which hold the drive-shaft housing to cam-shaft housing. Examine the bearings and bearing surfaces, and also the splines at lower end of shaft, making sure that none of these show excessive wear. The proper diametrical clearance of the two upper bearings should be about 0.002 inch. If it becomes necessary to put in new drive-shaft bushings, they should be oiled and pressed in tightly. They should then be carefully reamed to size which will depend to a certain extent on amount of wear on shaft bearings. The normal size reamers should be, upper 0.8755 inch, lower 1.1255 inch, and as wear of shaft will be very slight, these sizes will ordinarily be used.

### REPLACING CAM SHAFT.

In assembling cam-shaft unit, the same care should be taken as in disassembly. All parts should be thoroughly washed in kerosene and dried with an air jet if possible. If any parts have needed replacement, make sure that new parts are of the proper sizes, and clearances are within the limits specified heretofore. It is, of course, natural to assume that the minimum clearance, end play, or gear lash, as the case may be, should be followed as closely as possible, as the maximum is in reality an allowance for wear. For instance, if a new cam-shaft bearing is needed, its outside diameter should be carefully determined as well as clearance on the cam shaft. When it is in place in the housing it should be free enough so that the lock screw hole may be lined up by inserting a drift and prying lightly on it. It should not be so loose, however, as to shake or show any perceptible movement unless under a slight pressure.

### GENERATOR AND LOWER CAM-SHAFT DRIVE-SHAFT ASSEMBLIES.

A few words are not amiss here, in regard to the two assemblies known as generator drive-shaft assembly and lower cam-shaft drive assembly, located in crank case at the gear end. The removal of these will be taken up later, as usually it is inconvenient to remove them at this stage of the disassembly. However, they are sometimes not fitted quite as tight in their positions as they should be, and in that case come out very easily. In case they do lift out very freely now, inspect and care for them in prescribed way. If they are fitted properly, do not attempt to remove them now by prying or forcing.

### REMOVE COOLING SYSTEM CONNECTIONS.

The cylinder water inlet manifolds and extensions are easily removed by releasing hose clamps at water-pump outlets and cylinder-inlet elbows. It is not necessary to remove all hose clamps in order to remove manifolds, but as hose connections are taped and shellacked, all must be removed before reassembling, so it is best to remove them at this time. Note condition of these connections, and if any are damaged in any way, make provisions for replacing them, as no possible chance of leakage must ever be taken. Hose clamps must also be examined closely and new ones provided to replace any showing stripped threads or damage of any kind. It is best to remove and lay aside the two crank-case breathers now, as they will be in the way of other work a little later on.

### REMOVE WATER PUMP.

To take off water pump, it is only necessary to remove four nuts and washers from studs which hold pump to crank case, when it may be drawn off by hand. To disassemble water pump, remove the eight nuts and washers from studs which hold pump cover to main body of pump and remove cover. Do not pry under edge of cover, as doing so will injure the surface of joint, which must be absolutely true and tight. A thin gasket is placed between cover and pump to insure a water-tight joint. It may be necessary to use a little force to break the joint, as water will naturally leave a certain amount of deposit inside the pump. A safe method is to tap the cover lightly with a rawhide or wooden mallet, all around the inlet connection, at the same time pulling firmly on it with the hands. Remove bronze nut from water pump shaft and draw off impeller by the special puller which should be provided for the purpose. Take care that the gear puller is threaded on squarely and turned up to cover all threads, as otherwise the threads on impeller hub will be injured or stripped entirely. A small key will be found in keyway of shaft.

which must be taken out before drawing shaft from bearings. Make sure that impeller hub fits snugly on shaft, and keyway is not worn. If slightly worn because of a loose impeller, a new key may be fitted; but if much wear is shown, both a new key and impeller must be used. Examine the water pump shaft. If it is rusted enough to be rough, it should be replaced, as a rough shaft tears away the pump packing, causing dangerous leaks. If only slightly rusted or roughened, it may be smoothed down by the use of fine emery cloth and oil. After polishing a shaft by this method, carefully wash it with gasoline to remove all traces of emery that may remain. It is advisable, if possible, to use new packing each time pump is overhauled, so remove brass glands and packing from both sides of pump. See that these glands move freely in place, as the compression of the spring against them must move them up gradually as packing wears away, and a failure to do so will cause leakage quickly. Examine spring and if it is found to be badly rusted or weak, replace it with a new one. Examine ball bearing next to pump shaft gear and see that it is in good condition, not rusted, ball races scored, or no balls broken or injured.

### ASSEMBLE PUMP.

To reassemble pump put shaft and ball bearing in place and wrap about 8 or 9 inches of three-sixteenths inch graphite filled cotton rope packing around it, pressing same down into the packing box by use of the gland. Before putting in spring, it should be compressed and tied with small wire or twine. Place spring on shaft and over it the second gland, and a similar piece of packing. Pump body should now be put in place being careful to get packing properly placed in stuffing box. Insert key in keyway of shaft and draw impeller on by use of the nut. See that impeller hub fits snugly, and that nut is drawn up tight and cottered. Cut and draw out wires or twine from spring, and see that it does not bind or catch at either end. The water pump shaft should turn freely now and have not more than 0.010 inch end play, with pump sections clamped together. Put a good gasket on the pump cover before placing it on pump. Draw all nuts up snug and evenly and cotter them. A slight amount of shellac on one side of the gasket will do no harm but never use white lead or other filler on the pump joint, as it will set so that the pump may be ruined in trying to break the joint. If joint surfaces were uninjured and a new gasket used, the pump will not leak.

### REMOVE CYLINDERS.

Cylinders may be dismounted by removing the nuts from cylinder hold-down studs. Notice that the nuts on studs between cylinders

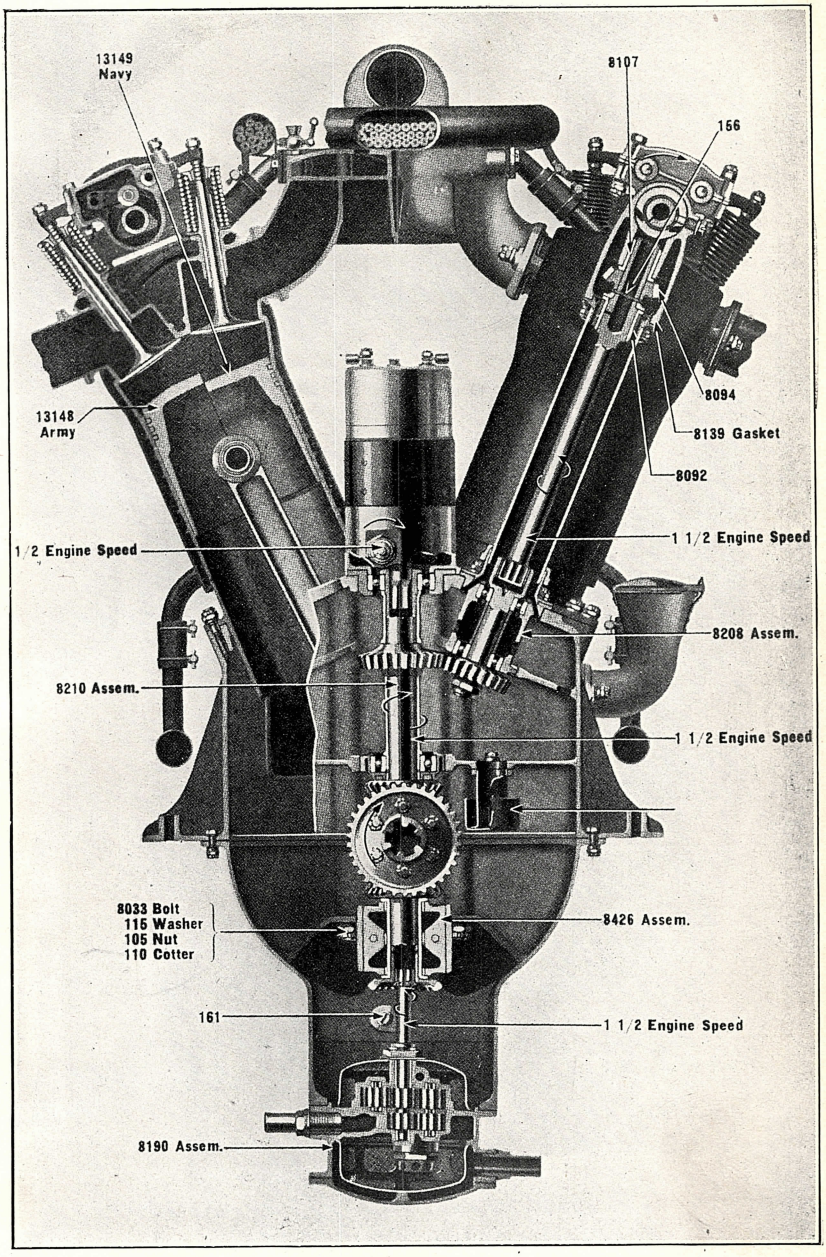

13149
Navy
8107
156
13148
Army
8094
8139 Gasket
8092
1/2 Engine Speed
1 1/2 Engine Speed
8208 Assem.
8210 Assem.
1 1/2 Engine Speed
8033 Bolt
115 Washer
105 Nut
110 Cotter
8426 Assem.
161
1 1/2 Engine Speed
8190 Assem.

FIG. 13.

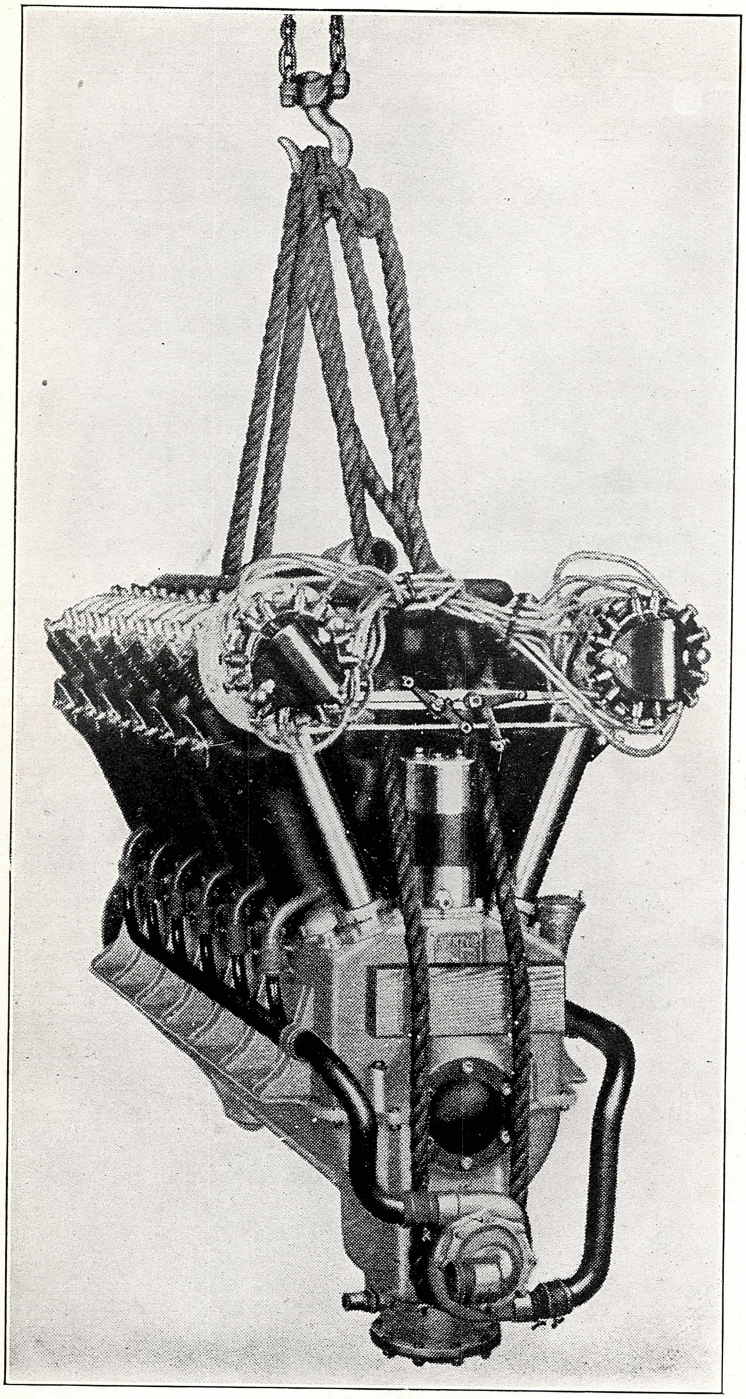


FIG. 14.

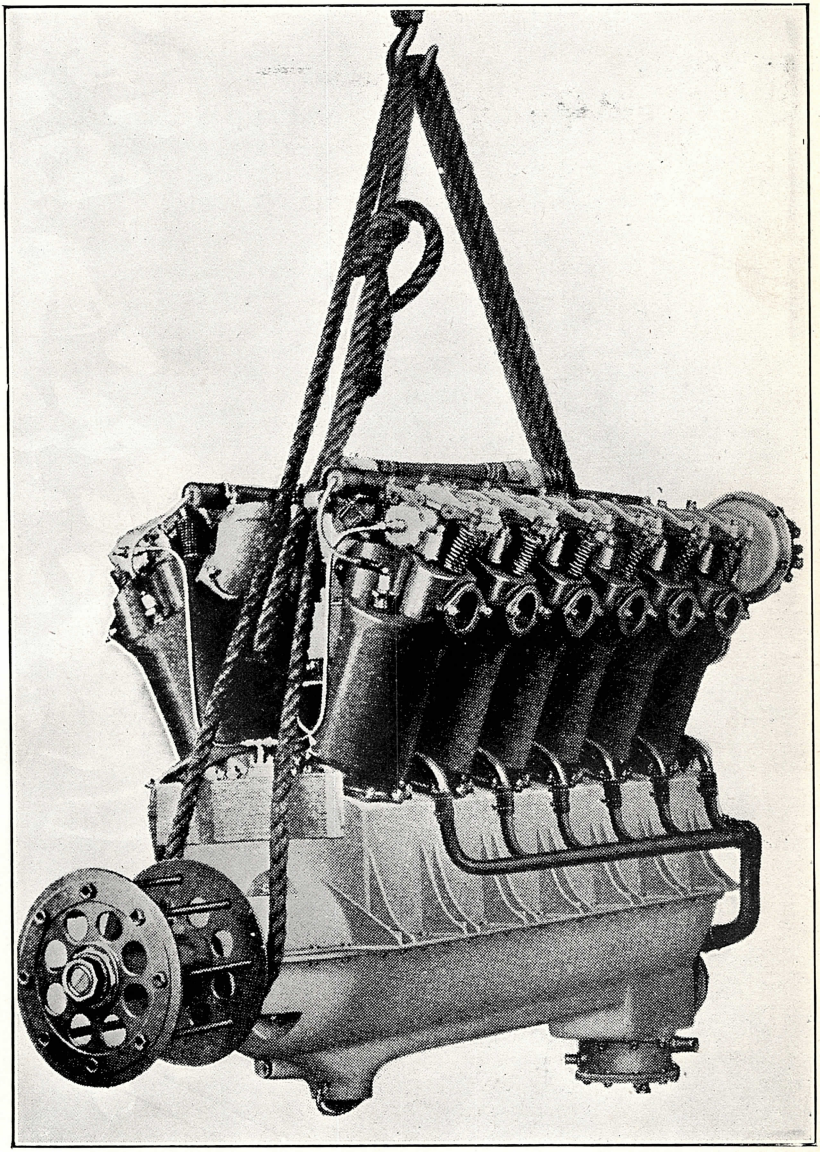


FIG. 15.

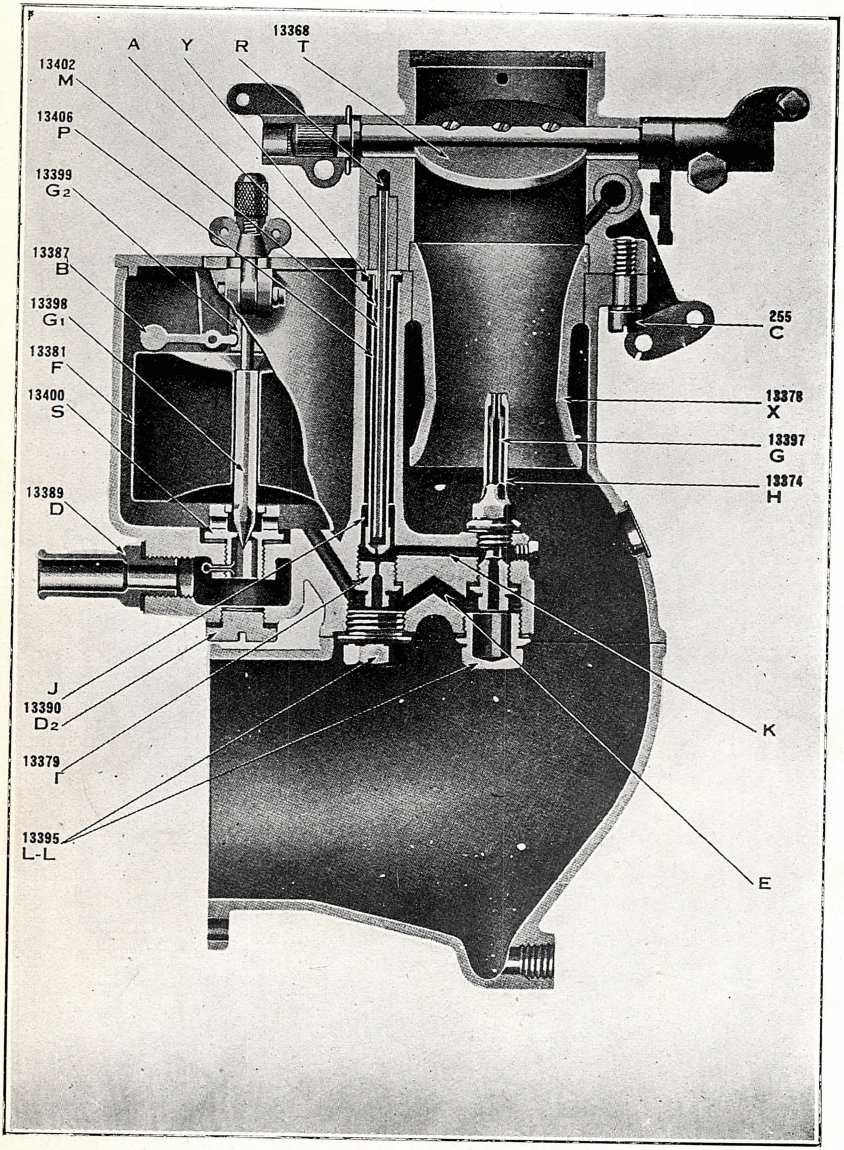

13368
T
A
Y
R
13402
M
13406
P
13399
G2
13387
B
13398
G1
13381
F
13400
S
13389
D
J
13390
D2
13379
I
13395
L-L
255
C
13378
X
13397
G
13374
H
K
E

FIG. 16.

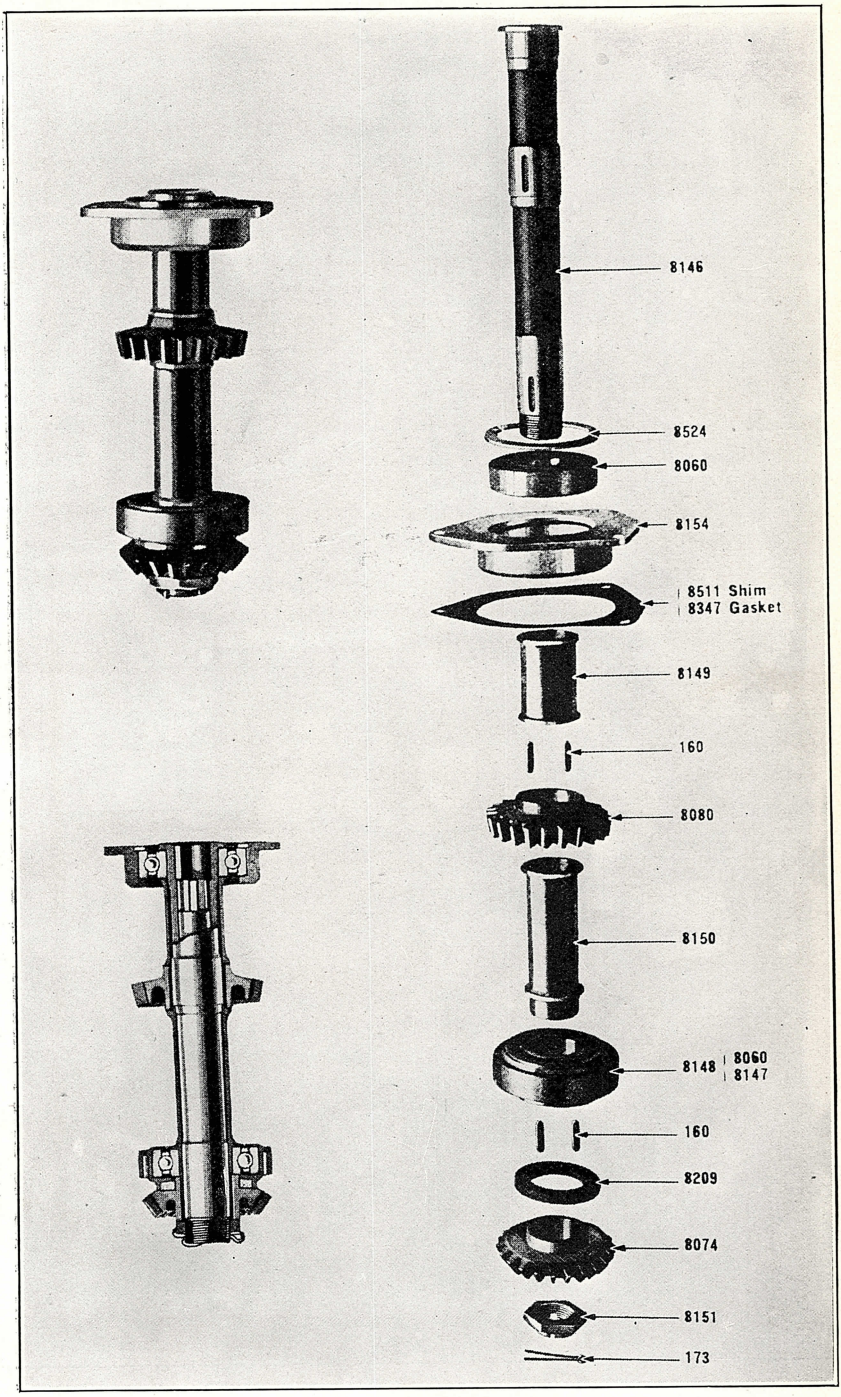

8146
8524
8060
8154
8511 Shim
8347 Gasket
8149
160
8080
8150
8148
8060
8147
160
8209
8074
8151
173

FIG. 17.

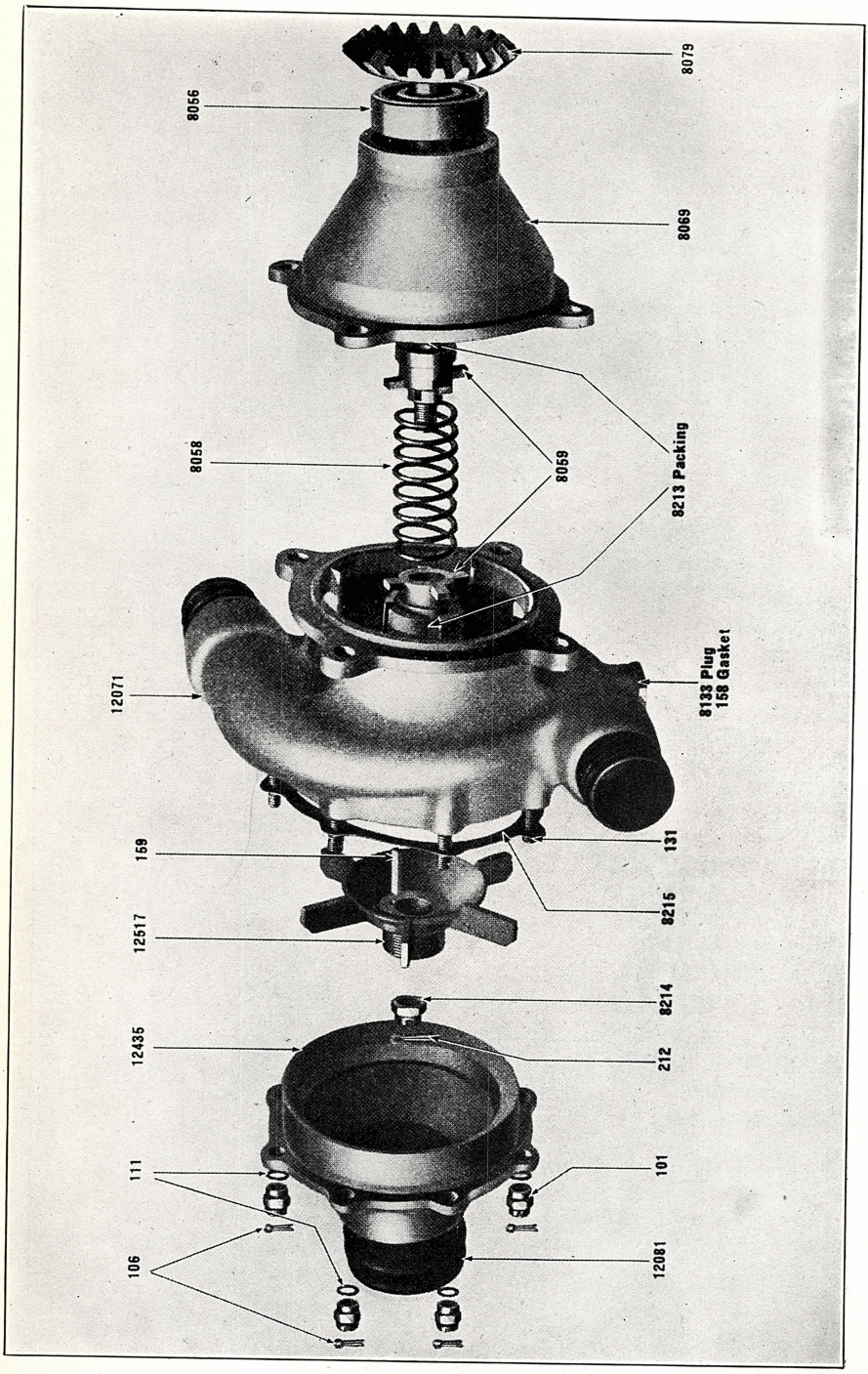

8079
8056
8069
8058
8059
8213 Packing
12071
8133 Plug
158 Gasket
159
131
12517
8215
8214
12435
212
111
101
106
12081

FIG. 18.

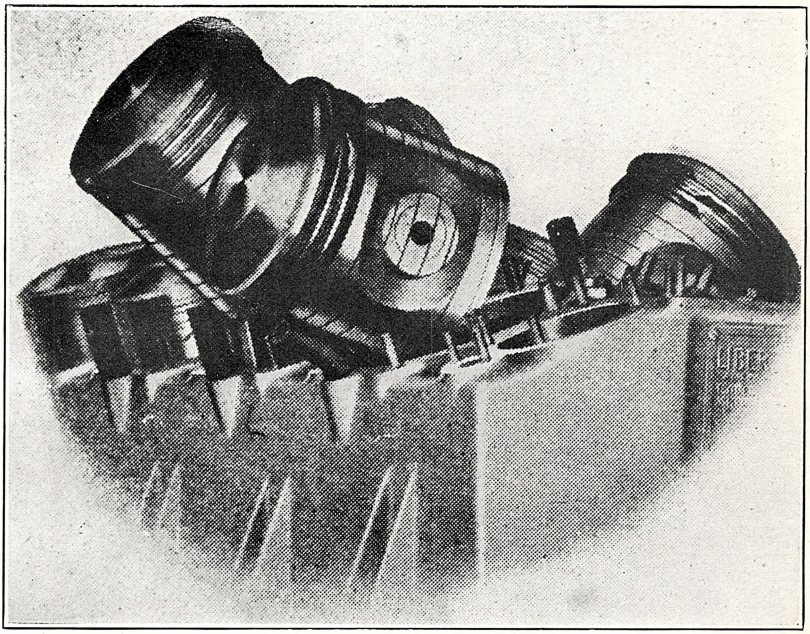


FIG. 19.

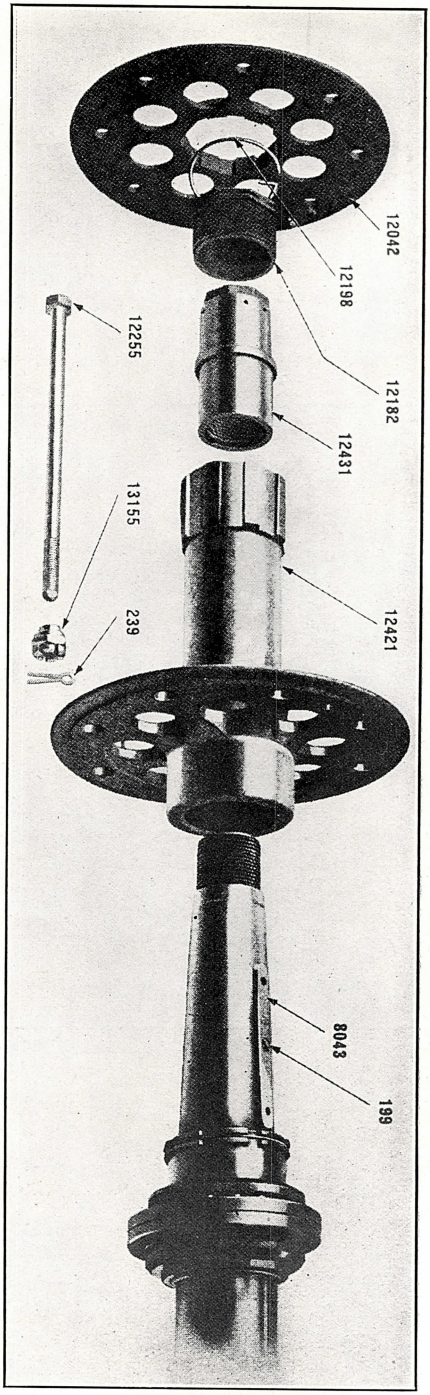



FIG. 20.

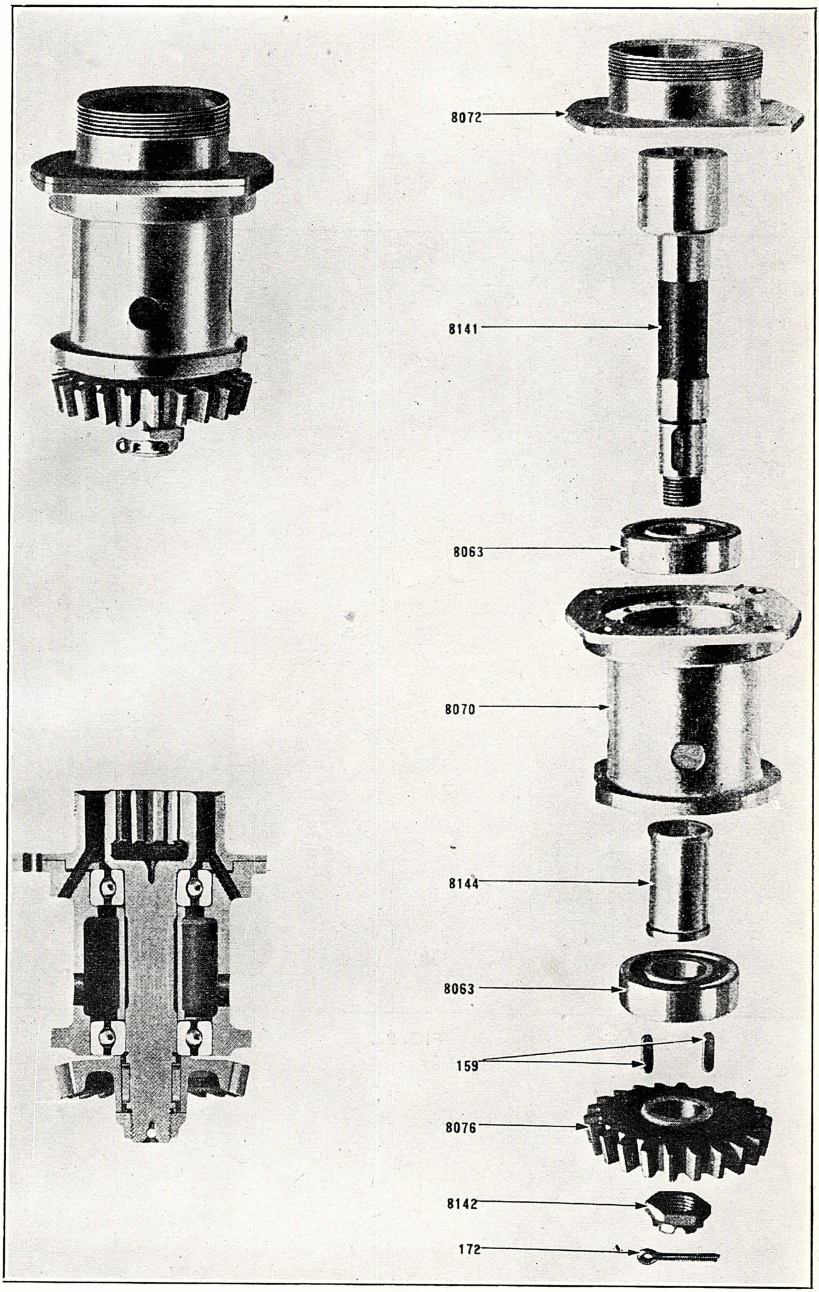



FIG. 21.

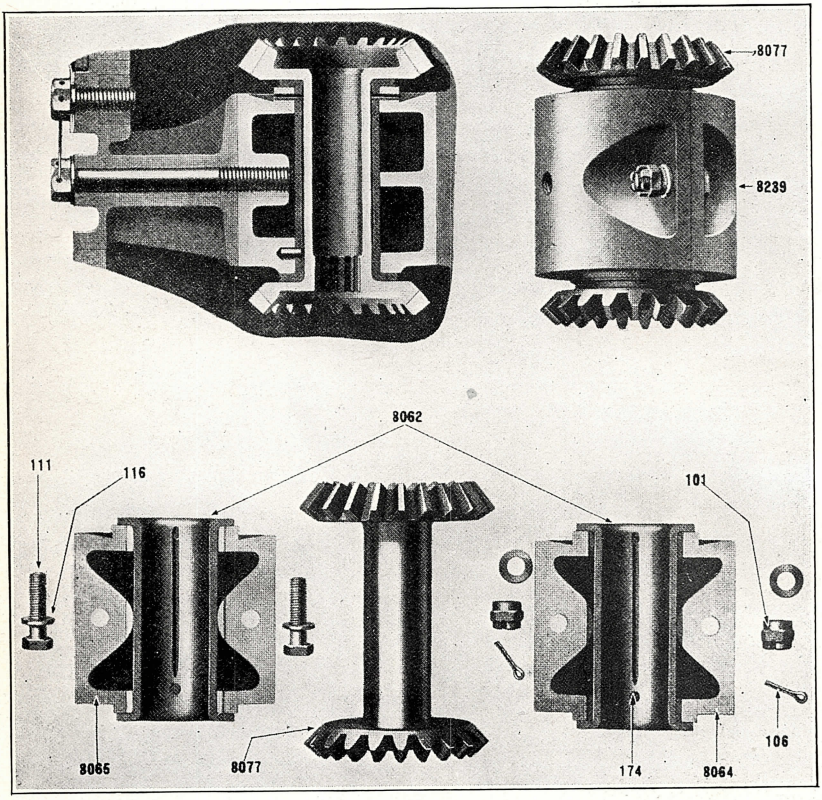



FIG. 22.

have a wide base, so that they have sufficient bearing surfaces on each of the two flanges. The factory cylinder number will be found stamped on edge of base flange, and also the number showing location of each cylinder on the engine, as 6R, denoting No. 6 cylinder on the right bank. Numbers start at the gear end. Remove cylinders one at a time, being very careful that pistons do not drop down against studs, as many pistons are damaged in this way. Two men should work together, one lifting the cylinder while the other cares for piston. Immediately after cylinder is lifted from crank case, short stubs of rubber hose must be placed over two studs on opposite sides where pistons are apt to strike. If either water or air pressure is available, water being preferable, test each water jacket at about 10 pounds pressure. Any leaks may be easily repaired by use of a small oxy-acetylene torch. A frequent point of trouble is around the spark plug opening, as the plug wrench is often pressed down against the cylinder and sometimes breaks or wears away the metal filled in around that point in the original welding of water jacket. Take particular notice of this point, even though it does not leak, as it may be damaged so that a leak will soon develop. Carbon should be removed from combustion chamber of the cylinders by use of scrapers, taking care that cylinder walls are not marred by striking or scratching with scrapers. Examine cylinder walls carefully for scores, scratches, or excessive wear. The condition of pistons and rings will often give a very good idea of what to expect when going over cylinders. A cylinder which is scored or one that is worn out of round, should not be used except in very great emergency, and then only with permission of some responsible officer in charge of the work. Occasionally a cylinder may appear to be scored, but on close examination it will be found that the piston has seized slightly, causing a small amount of the piston metal to adhere to cylinder walls in the form of streaks up and down. Remove this metal with a soft scraper and carefully polish the streaks or spots which are slightly rough. Crocus cloth saturated with oil will be found best for this purpose as it is not coarse enough to scratch the surface if properly handled. Thoroughly wash the cylinder with gasoline after this operation to remove any possible gritty substance which might cause rapid wear.

### REMOVE, INSPECT, AND GRIND VALVES.

The valve-spring compressor furnished in tool kit will be found a very handy tool if properly used, so that Liberty valves may be removed with ease. Turn compressor screw entirely out, slip base of compressor frame under lower valve-spring collar and turn compresser screw down, at the same time holding valve up by inserting

fingers through port, holding them, or by placing hand inside cylinder against valve head. When spring has been compressed sufficiently to uncover valve-spring collar keys, which fit into the conical opening of upper collar, they may be removed with the fingers. Valve will then be released so it will drop out, and care must be taken that it does not strike cylinder walls, as the valves are of much harder steel than the cylinders and will injure the surface if they happen to strike it. Valves have the cylinder number etched on them, and also "Ex." or "In.", denoting exhaust or inlet, so there is no chance of placing them in the wrong position. Inside springs of both intake and exhaust are alike, but outside spring of exhaust is heavier than intake. Exhaust outside spring has only 10 coils, while intake has 12, so they may be easily distinguished.

The outside exhaust spring should exert a pressure of 45 pounds, and the outside intake spring a pressure of 23½ pounds, when compressed to 2¼ inches. A slight variation is allowable, but any spring which falls as much as 3 or 4 pounds below this figure should be discarded. An ordinary platform scale may be easily arranged to weigh these springs, and should be used whenever a motor is overhauled. Clean valve stems and valve-stem guides carefully, removing all gummed and burned oil, and noting their condition. The exhaust stem should have about 0.005-inch diametrical clearance in its guide, and intake should have about 0.003 inch. A limited amount of wear will have to be allowed for, but if valve guides are worn to any extent, especially the intake, they should be replaced. Valve guides are made of cast iron, pressed into place in the steel cylinder. With the proper tools, they may be easily removed and replaced, but ordinarily the mechanic overhauling the motor is not equipped to do so. When guides become so worn as to require replacement, unless proper equipment is available, the cylinders should be set aside for shipment to base repair shop and entire new cylinders used. Remove all carbon from valve heads and examine both valve seats in cylinder and valve faces. If surfaces are smooth and appear to be a tight fit, place valve in cylinder, put on spring, and test for tightness with gasoline. To do so, either lay cylinder on its side and nearly fill the port with gasoline, or invert cylinder. If there is no seepage of gasoline, try turning the valve around in three or four positions. If it is gasoline-tight in all positions, it needs no grinding. The valve-grinding tool furnished with the Liberty tool kit will be found most convenient, with a light coil spring under the valve head to lift valve from seat. This spring should have just enough tension to lift valve and tool off the seat when pull is released. Valves should be ground only as much as necessary to secure a gas-tight fit. A few small pits here and there do no harm, and if valve and seat show a smooth contact of over half their width, all

around, and are gasoline-tight, no more is necessary. Badly warped or burned valves should be replaced, and seats of such should be cleaned up with a reseating tool. Be very careful to wash off all grinding compound from valve and cylinder before replacing, and oil valve stem and guide. In replacing valve assemblies in cylinders, use valve-spring compressor in the same manner as for removal of springs. See that valve-spring collar keys are placed properly in position.

### DISASSEMBLY OF CRANK-CASE.

Before turning the case over, the nuts and washers should be removed from 16 main crank-shaft bearing bolts, as they are unhandy to get at after motor is turned over. When these have been removed, turn case over and next remove all bolts from crank-case flanges, and four end crank-case bolts. Also remove rear-end cover and gasket at this time, or gun synchronizer and air pump, which will be fitted to most motors. When all crank-case bolts have been removed and crank-shaft bearing bolts loosened slightly, watch for any signs of warping of the case valves. A nose over, very rough landing, or other accident on the field sometimes springs a motor case, and such a thing can often be detected easily at this time. Upper and lower halves of crank-case may now be separated, but proper care must be taken in doing so. No instrument of any kind should ever be inserted between halves of case to pry or force them apart, as the joint is lapped fit and must not be marred or sprung the least bit. Three men working together can handle this nicely, one lifting at each end of the case while the third taps the ends of crank shaft bearing bolts with a rawhide hammer or drift pin of brass. As these bolts are a fairly close fit in the case, lower half must be lifted evenly so as not to cause bending of the bolts or injury to the case itself.

While crank-case halves are separated do not lay tools on joint surfaces, or in making repairs or adjustments, do not allow any tools to strike against these surfaces, as to do so will usually scratch or roughen the surface, causing leakage, and possibly loose bearings or distortion of the case, if the injury is to any extent. Examine the crank-shaft bearing bolts to make sure they are tight in case and threads at upper ends are in good condition. Next remove connecting rods and pistons from crank shaft. Diametrical clearance of connecting-rod bearings on crank shaft should be 0.003 inch. There should be 0.020 side play on the crank pin. Examine all rods when removing, and determine which, if any, will need new bearing bushings, straightening, or replacement, making note of such. A certain amount of wear will have taken place, so that after several hours' running, the clearance will be over 0.003 inch. It should not be more

than 0.004 inch, however, and in case it is found to be more than that, the bushing should be replaced. Complete inspection and overhaul of connecting rods will be taken up in another paragraph. Note the numbers stamped on webs of connecting rods and positions in which they are located. Both rods and caps are numbered at the joint, on one side, and must be placed so that these numbers coincide. The bearing bushings are usually numbered to correspond with the rods and caps, and therefore all three numbers must come in their proper positions. As soon as rods and pistons are taken from crank shaft, place rods together in pairs on a suitable rack, with caps, bolts, and nuts in place, so there will be no chance of injury or loss of any parts. Lift crank shaft from upper half main bearings, wash it thoroughly for examination, and lay aside on a solid support. Remove two lower cam-shaft drive shaft and generator drive-shaft assemblies at this time. These may be taken out by tapping lightly on lower end of shaft with block or fiber drift. Take care that these assemblies do not drop on the floor and become injured, as it is likely to happen when tapping on them. Remove oil pump from lower half of crank case by removing nine nuts and washers from oil-pump flange studs. Lay aside oil pump, as it is well to complete crank-case inspection now. Thoroughly wash both halves of crank case with kerosene and dry with an air jet, if air pressure is available. Remove plug at front end of main oil lead and blow out all oil passages carefully. Examine case very closely for any signs of cracking or weakness which might have developed from landing or possibly a fall. If there is any possible reason to believe that the case has been sprung, test the surfaces with a straight edge or large surface plate, if possible to get one. All bearing bushings will not be examined to determine the condition of bearing surfaces and amount of clearance. The diametrical clearance of main bearings should be 0.003 inch, but after running a number of hours some wear will occur. Bearing bushings should be removed from the case, under contact surfaces wiped clean and dry, and replaced. Note that each one is numbered on the end, to correspond with its position in the case.

### CARE AND FIT OF BEARINGS.

In order to determine the exact diametrical clearance of the bearings, it will be necessary to place two halves of crank case together and tighten nuts on crank-shaft bearing bolts. Inside diameter of each bearing should then be carefully taken with micrometer and compared with a like measurement of the corresponding bearing of crank shaft. If the measurements are properly taken, a true gauge of the diametrical clearance will be obtained. Bearings should show at least 75 per cent surface, and should not show any roughness, scratches, or scores. Student should apply the same reasoning when

inspecting these bearings as he has been taught to do on other motors. It must be understood, though, that this type of bearing is not to be scraped and fitted by the usual method, as there is no provision for taking it up in any way, and excessive clearance can only be overcome by putting in new bearings.

It is sometimes necessary to touch up a rough bearing slightly or to do so in order to remove particles of dirt or metal from the surface, but further than that, no scraping should be done. In a case where one or two bearings were in very bad condition, new ones might be scraped in, if proper care were taken in lining them up and determining clearances. The factory method of reaming and fitting bearings will be taken up in another section of the course, so will not be discussed here to any extent. It will be easily understood by the student that it is impractical to follow ordinary method of bearing fitting on this motor, and that a method of reaming will have to be used, or a stock of bearings of various sizes held available. As soon as bearing inspection is completed or new ones placed and fitted, lay crank shaft back in the case, as it is less apt to be injured when in the case than on the bench.

### CONNECTING ROD AND PISTON OVERHAUL.

Pistons will be removed from connecting rods for inspection. The aluminum piston-pin retainers may be driven off easily with a small rod or drift inserted through piston pin from opposite side. Piston pins may be removed by the use of brass faced drift which is provided in the tool kit. These pins should fit so that they may be forced out, by pressure of the hand, or not tighter than a light driving fit. Numbers designating the cylinders in which pistons belong will be found stamped on the side of pistons, in the depression around piston pin bosses. This number should face toward the gear end of motor, as should also the numbers stamped in the web of connecting rods. It is best to remove all pistons from their rods at one time, giving all the same care and inspection. Clean all carbon off the piston heads by the use of a soft scraper or kerosene and a steel wire brush, which is not so stiff as to scratch the piston surface. Any amount of roughness tends to aid in the formation of carbon, so that it is important that all is removed, and that there are no scratches made on the piston heads. Although aluminum alloy pistons do not accumulate so much carbon on their under surfaces as cast iron, there is apt to be some, and no matter how small an amount, it must be removed. Considerable carbon accumulates in the ring grooves, all of which must be removed. Do not use a hard sharp tool for this purpose, as it will cut away some of the metal, widening the grooves in places. A tool made of aluminum or hard wood or a narrow steel wire brush

should remove all carbon accumulation if carefully used. If carbon deposit is light and soft, it may be removed by inserting a piece of wood through the ring gap. In doing this, take care not to spread the ring to any extent as the ring is easily broken in this way. Rings should move freely in their grooves, with a clearance of 0.003 inch in upper groove, 0.002 to 0.0025 inch in middle groove and 0.0015 inch in bottom groove. The ring gap should be 0.025 inch or slightly more. When rings are removed from grooves they should be replaced in the same grooves with the same side up. It will be noticed that the middle ring is cut at the opposite angle to the upper and lower, and in case new rings are fitted this should be remembered. If rings are properly ground they will show an even bearing on the outside surface, and after a few hours running there should be no spot on the ring which is not smooth and clean, denoting a perfect contact surface. Any rings found with dark sections on their outside surface should be replaced, and new rings should be tested with Prussian blue before assembling the pistons and connecting rod for use.

Liberty pistons are allowed more than the average clearance, owing to the high compression, causing greater heat expansion. The proper amount must be allowed or pistons will seize and cause serious scoring. The skirt of piston should have 0.020 inch diametrical clearance, lower land 0.025 inch, middle land 0.030 inch, and top of piston 0.035 inch, in the cylinder. Aluminum alloy pistons have a natural tendency to score slightly, and if the scoring or scratching is not deep, and does not extend above the lower ring, it will cause no trouble. Pistons which are scored to any extent should be smoothed up with a medium oilstone and plenty of oil, rubbing lightly and taking off only the metal which forms ridges above the surface. Examine these pistons very closely for wear on the outside surface, as uneven wear will indicate bent or twisted connecting rods. Make note of any that show uneven wear, and when fitting connecting rods do not fail to test these rods and straighten them before assembling. When replacing piston-pin retainers, make sure their surfaces do not extend beyond the surface of the piston. Determine this by laying a scale or straightedge along the piston over the retainer. If it becomes necessary to replace any pistons, the new ones must be of the same weight as ones already in motor. In the depression around piston-pin bosses will be found numbers (not the cylinder number), which indicates the weight of that piston in ounces above 3 pounds. If the motor has run for some time, weigh the pistons carefully, as natural wear may lower the weight slightly.

### CONNECTING ROD INSPECTION AND OVERHAUL.

As the connecting-rod bearings were previously checked for diametrical clearance on the crank pin, as well as side play, these points

are already known, and to a great extent will determine what is to be done next. We understand that all bearings should show a 75 per cent surface, and any that do so with a diametrical clearance of 0.003 to 0.004 inch do not need replacement, unless the outside surface on which the plain end bears is worn down so as to create too much clearance on that bearing. The diametrical clearance between the bushing and plain end bearing of connecting rod should be 0.005 inch, but may be slightly more on account of natural wear. The bronze surface should be clean and smooth and not out of round. Any bushings that were found to have too much clearance, or are now found to be unfit for use owing to excessive outside wear, cracks, rough surface, etc., will now be replaced with new ones. First fit the new upper half bushing in forked end of connecting rod, making sure that it seats properly and is not half away by the dowel, then fit other half in the caps. The caps will all have numbers corresponding to their numbers on the rods, which must be placed together. Place rod and caps together, observing the fit of the joints as bolts are drawn up. Two halves of bushings should fit snugly together, as should face of caps and connecting rod; that is, all should bear equally at all points. If proper mandrels are available, it is best to scrape bearing to fit a mandrel 0.003 inch larger than crank pin on which it is to run. If no mandrel is to be had, bearing may be fitted directly to crank pin by the usual method, using shim stock to determine clearance. Be careful to remove a uniform amount of metal at both sides of the bushing, so as to keep the connecting rod in proper alignment. Take care to keep the corners of bushing rounded off, so there is no bearing on the fillet of the crank pin. To fit plain end connecting rod on bronze bushing surface, assemble forked end rod, drawing up bolts to proper tension. Measure inside of plain rod with micrometer, and also outside of bronze. The clearance should be 0.005 inch. If it is found to be about this amount, or over 0.004 inch, all that will be required will be to touch up the bearing bushing at the joints, with a very fine file, and make sure the bearings are not out of round. Test fit of bearing with Prussian blue, placing blue on surface of rod bearing, and smooth down any high spots with very fine file.

All connecting-rod bearings which are fitted with new bearings must be tested for alignment, and it is well to test all others as a measure of safety. Any rods on which the pistons show uneven wear are known to be out of line and must be straightened. Procure two mandrels about 12 inches long which will fit snugly in upper and lower bearing bushings, and with the aid of a surface plate and dial indicator test for distance between ends of mandrel. It is also well to test by the use of a square along the edge of the connecting rod. To determine whether or not the connecting rod is twisted, lay

the mandrels on parallel bars on a surface plate. Plain-end rods may be tested for alignment by placing on forked-end rods, with a strip of shim stock of sufficient thickness to take up all clearance on underside. Place the smaller mandrel through piston-pin bushing and test on surface plate as before. Any twist or bend may be removed by clamping the rod in a vise and springing with a bending bar, which is a heavy bar, notched at the end so as to fit over the connecting rod. Piston-pin bushings should have 0.0015-inch diametrical clearance on the pins, and all should be examined closely. This amount of clearance will allow a free movement without shake when the pin is oiled. Too great a clearance will cause bushings to pound out, and not enough clearance will cause bushings to seize the pin when heated, causing excessive wear on piston bosses. Surface of bushing should be smooth and free from scratches or scores. If it is necessary to replace bushings, the new ones should be oiled and pressed into place tightly. It will then be necessary to ream them carefully until proper clearance and smooth surface are obtained.

### CRANK SHAFT INSPECTION AND OVERHAUL.

Crank shaft should be very carefully inspected, as it is one of the most vital parts of the motor, and on its condition and operation depends the life of the pilot. Many have an idea that a crank shaft is unsafe after a certain number of hours' use, but just how long this is can hardly be determined, and it is up to the mechanic to give the shaft as thorough an examination as possible. All bearing surfaces should be perfectly smooth, and a shaft which has had more than one overhaul, or possibly over a hundred flying hours, should be examined closely with a microscope to determine if any cracks have developed, or what is termed crystallization has set in. If shaft is thought to be out of alignment it should be swung in a lathe and tested with a dial indicator. As a rule not over 0.005 inch out of alignment should be allowed, but in emergency a shaft with slightly more might be used. If any bearing surface is slightly roughened or scored, it may be smoothed with a fine mill file and polished with fine sandpaper and oil, or crocus cloth and oil. Filing must be done very carefully, so as not to get shaft out of round, testing with micrometer from time to time. This only applies to very slight scoring or roughness and should never be attempted on a shaft which is damaged to any extent. Examine the thrust bearing for end play and note its general condition. Balls and races should be bright and smooth and must turn absolutely free, with no binding or roughness at any point. A slight end play is necessary for the proper operation of the bearing, but if there has been excessive wear it should be replaced with a new bearing. Occasionally ball bearings will be

found rusted. If either the balls or races are rusted on the contact surfaces they are unfit for use. The ball cages should be examined, as sometimes they break, causing serious damage to the bearings. Make sure that the small lock screw through retaining nut is down securely and that the locking wire is down squarely in the slot. Examine the plug in propeller end of shaft and also all plugs at the ends of main and crank-pin bearings. On the new type motors it is possible to remove these plugs by removing the bolt which binds them together, and they should be taken out in order to remove any collection of sediment or dirt within the shaft. In replacing them, see that all gaskets are intact, as there must be no oil leakage at any point. Examine the crank-shaft gear and see that it is fitted tightly and does not show excessive wear. If motor is fitted with gun synchronizer, take notice of condition of splines inside gear hub.

### REMOVING THE HUB.

If thrust bearing needs no repair or replacement it will be unnecessary to remove the hub, and it should not be removed except when absolutely necessary. To remove the hub, it will be necessary to heat it, and in doing so apply the flame of a blow torch to the barrel of the hub near the flange, moving it around so the heat will be distributed evenly. The lock nut (largest one) and retaining nut (longest one) are used as a puller, so it is not necessary to have other tools than the two special hub-nut wrenches supplied in the tool kit. Place both wrenches on the nuts, screw out the lock nut about a turn, and then screw out the retaining nut, holding the lock nut and crank shaft stationary. A few turns will free the hub from tapered shaft so that it may be drawn off easily. To replace hub, heat it thoroughly by placing in boiling water a few minutes. See that key and keyway are in good condition and that top of key has at least 0.010 inch clearance from bottom of keyway in the hub. Also see that the surface of shaft is absolutely smooth and free from rust or dirt. Wipe surface of shaft with a very slight amount of light oil, to avoid rust, and after wiping interior surface of hub with a clean dry cloth, place it snugly on the shaft.

### LOWER CAM-SHAFT DRIVE SHAFTS AND GENERATOR DRIVE SHAFT ASSEMBLY.

These shaft assemblies under ordinary conditions will not be taken apart, but as some defect may appear it is well to know their construction. The lower cam-shaft drive shafts may be taken apart by removing the gear at lower end, by the use of a gear puller, lifting out the two keys and drawing shaft out through ball bearing. By drawing off the spacer, the upper ball bearing may also be removed. Bearings should not have more than 0.004 inch end

play and neither balls nor races should be used which are rough, rusty, or show excessive wear. The gear and splines in upper socket should be examined for wear. In removing shaft, do not attempt to drive it out through the gear, as to do so will injure the ball bearing. A gear puller for such work should be provided. Generator drive shaft assembly is very similar to cam-shaft drive shaft assembly and is taken apart by the same method. One or more metal shims will be found between upper bearing container flange and crank case. These are so placed to procure the proper clearance between gears, and must be kept in good condition for replacement. Remove gears with gear puller and remove keys from shaft before attempting to remove bearings and spacers. Both gears and splines in upper socket should be examined for wear. Ball bearings should not have more than 0.004 inch end play, and should be examined the same as mentioned for all other ball bearings. In reassembling, draw lower nut up tightly so there is not a chance for gear or spacers to loosen up.

### WATER PUMP BEVEL DRIVE GEAR.

By removing cap screw from crank case, just below rear end cover plate or gun synchronizer, bevel driver and housing may be withdrawn through oil pump opening, in bottom of crank case. Remove two bolts and separate housing, thus exposing the bearing bushings. The driver shaft should be perfectly smooth and free from scoring. The bearing bushing should show no signs of cutting, and if any particles of dirt are imbedded in the surface they should be removed carefully with a scraper. The end play in bearings should be from 0.005 to 0.008 inch, and diametrical clearance about 0.002 inch. In reassembling, the wider faced gear must be placed at upper end of housing, which is the cupped end. It will be noticed that this cup lubricates the bearing, and if it were placed wrong end up, the oil would not reach bearing. Examine both gears for excessive wear.

### OIL PUMP DISASSEMBLY AND INSPECTION.

By removing 10 bolts from cover flange, it may be lifted off pump body, which releases lower oil screen. The pressure release, or by-pass valve, may now be removed by use of special wrench provided in tool kit. Screen should be thoroughly cleaned of all gummed oil and sediment which may have accumulated. By-pass valve should be carefully examined, and if the engine log book is available, the pressure it has been maintaining should be looked up. The oil pressure at maximum motor speed should be about 30 pounds to the square inch. If the pressure runs lower than this and valve

head has holes drilled through it, it is advisable to solder up one or more holes. If there are no holes, it will be necessary to place shims under the valve, creating more spring tension. If pressure runs too high, and valve head has no holes, it will be necessary to drill one or more small holes, about No. 50 gauge drill, through head, close to stem. Remove the oil pump shaft and examine the splines of both ends for wear. Bend down the ears of lock washer, and remove nut which holds upper oil screen. Thoroughly clean this screen, and see that it is not broken. Remove four bolts which hold down upper oil pump housing, and lift same from over the return pump gears. After cleaning this covering, and three gears, place the gears in cover, with bearing pins in place, and examine them as to clearance. It should be not over 0.004 inch, and the end play not over 0.003 inch. Gear teeth should be perfectly smooth, and mesh freely at all points. Lift the separating plate, which will expose the pressure pump gears. These also should be examined as were the other three, the same clearances applying to all. The order of assembly is just a reversal of the disassembly. Make sure that the gears are in their proper places and right side up. Bolts which hold down upper oil pump housing must be placed with heads upward, as by-pass valve must be secured by a wire to one of these bolt ends, through cotter hole. If old cover gasket is not in perfect condition replace with new one. Draw all cover bolts up tightly. Lower cover oil drain plug should be examined to see that threads are not stripped. New type plugs have a wing through which a safety wire must be placed, leading to one of the lower cover bolts as a measure of safety. If the ears on upper nut lock washer are injured from bending, so there is any possible chance that they may not hold the nut, replace washer with a new one.

## Chapter IV.

# REASSEMBLY OF THE LIBERTY MOTOR.

### WORK PRELIMINARY TO REASSEMBLY.

Before beginning the reassembly of motor, all repairs and adjustments should be made. In case any parts needed for replacements or repairs were short at the time they were wanted, they should have been ordered and ought to be in stock now. Procure any such parts and complete all remaining work necessary before commencing the reassembly of motor. No matter how well the work has been done, or how carefully inspected, mistakes may have been made, so a careful final inspection of every detail should be made at the time it is placed in position. If two or more men are working on the same motor, it is well for one to check up on the work of the other, for though one may be no better workman than the other, either are likely to detect small details which may be overlooked by the other. As it has been possibly several days since disassembly of the motor was begun, a certain amount of dust has accumulated on all parts. This may not be visible to the eye, but nevertheless it is there, and may consist of particles of emery, sand, concrete, metal filings, etc., all of which are very injurious to bearing surfaces. Every bearing surface, and all parts, which will be inside the motor, or come in contact with the oil, must be carefully washed and dried before being assembled in the motor. Special care must be taken to wash out all oil passages and after doing so, to remove all kerosene from them. If air pressure is available, an air jet should be used for blowing out passages, and drying surfaces. Never use cotton waste for wiping any part of the motor. If cloth of any kind is used, wipe off with the bare hand any lint which is left.

### CRANK SHAFT PLACING.

Before placing crank shaft in bearings of upper half of crank case, wipe out all bearings and oil freely with clean, medium heavy oil, forcing a small quantity of oil into each passage through bearing bushing, and enough into each main and crank-pin bearing to fill the hollow crank shaft. Also pack the thrust bearing with clean vaseline, not ordinary cup grease, making sure that it is forced down around the balls and between the races. Be sure that the shaft is lowered squarely into case and that thrust bearing sleeves seat prop-

erly in the case, fitting snugly so there is no end play. These collars are of various thicknesses, so that a snug fit may be obtained as well as proper clearance between cheeks and ends of bearing bushings. This clearance should be 0.020 inch at each end of the bearing, and not two-thirds front and one-third rear, as taught on some other motors.

### PLACING CONNECTING ROD AND PISTON ASSEMBLIES ON CRANK SHAFT.

See that stubs of rubber hose are on all cylinder hold-down studs against which any pistons can strike, before placing any connecting rods on the crank shaft. Pistons and rods should be already assembled, and numbers stamped in the webs of rods must face the same way as numbers stamped in depressions around piston bosses. When placed on crank shaft, these numbers must face gear end of motor. Forked end rods are placed so they are on the right side of motor, when motor is right side up, which brings them to the left side when case is upside down, as now. Do not get confused on this point as rods must be reassembled the same as before taken down. Oil the crank pins, and both inside and outside surfaces of connecting rod bushings, liberally, with heavy oil. Place plain and forked end connecting rods which go on same crank pin, up through cylinder openings, spreading them, at a wide angle, so that plain end will pass freely through forked end, and lift the two into place together. Put on formed end cap first, drawing nuts up snugly and evenly, then put plain end in place and tighten nuts of same. Do not tighten up one or two nuts on one rod while others of that rod are still loose, as such a method will tend to distort the bearing. Turn nuts on until all are just down, but with no tension, then, one after the other, give them about a quarter turn, until all have the proper tension. It must be borne in mind that although bolts should be drawn up snugly so there is no possibility of a bearing loosening up, it must not be so tight as to create a self strain, or undue tension, which stretches the bolt and thereby weakens it to some extent, depending on the amount of tension. All nuts must be carefully cottered, using cotters of proper size and length. Ones which are too long must be cut to proper length, as the projecting ends are apt to interfere with the opposite rod. Heads should fit closely against nuts and bolt heads.

### ASSEMBLE TWO HALVES OF CRANK CASE.

Before placing two halves of crank case together, make sure that surfaces of both halves are perfectly clean and dry, so as to form a perfectly tight joint. On some of the newer motors, it is understood that shellac is being used in the joint, but no gasket is used in any

type. If shellac was found in joint of motor when it was taken down, surfaces should have been cleaned thoroughly, and should be reshellaced now, using only enough to insure a tight joint. When all rods have been assembled on the crank shaft, put lower half of crank case in position, and put in four end crank-case bolts. By tightening these four bolts first, the entire case will be drawn together. Next put in all crank-case flange bolts, using plain washers, draw nuts up snugly and cotter them.

### PLACE WATER-PUMP BEVEL DRIVER.

Put the water-pump bevel driver in place and secure with lock screw from outside case. Test the lash of gear with crank-shaft gear, allowing 0.005 inch as a minimum, and not over 0.010 inch. If a new gear has been put in, or for any other reason the gears mesh too closely, the lash may be increased by inserting a thin shim between end of crank shaft, and crank-shaft gear.

### INSTALL OIL PUMP.

Oil pump should be installed next, making sure that splines of drive shaft fit freely in splines of water pump lower bevel gear. A gasket is fitted between oil pump and crank case, and care must be taken that proper openings are left for the oil inlet and outlet passages. Draw all nuts up snugly and cotter them.

### TURN CRANK CASE RIGHT SIDE UP.

Put washers and nuts on upper ends of 16 main crank-shaft bearing bolts, and draw the nuts down quite tight, using the special socket wrench provided for these nuts. As these bolts bind together the entire crank case and main bearings, it is important that they be tight, and all at an equal tension. Cotter the nuts with proper size of cotters.

### INSTALL GENERATOR DRIVE SHAFT ASSEMBLY AND TWO LOWER CAM-SHAFT DRIVE SHAFTS.

Put generator drive shaft in place first, with proper shims under the upper flange to regulate gear clearance. There should be 0.015 inch lash between this gear and crank-shaft gear. Next put in two lower cam-shaft drive shafts, and secure by nuts on flange studs. The lash between these gears and gear on generator drive shaft should be .005 inch, while .015 inch is quite noticeable.

### PLACE ALL CYLINDERS.

If plugs have been removed from spark-plug holes replace them now to prevent any nuts, cotters, or other small parts from falling into cylinders. Cylinders should be absolutely clean and dry in-

side and must have the inner surface well coated with oil. Spread this oil with the bare hand, as lint will be left if a cloth of any kind is used. See that the gaskets on crankcase are clean and in good condition. Remove the rubber stubs from studs only as cylinders are put in place, to avoid any possible injury to the pistons. Pistons must be well coated with oil, and ring grooves must be filled, under the rings. Space the ring gaps equidistant, that is, 120° apart, and compress rings as cylinders are slipped on. Two men should work together, placing cylinder, one holding the piston firmly, so that it enters the cylinder squarely, at the same time compressing the rings as much as possible, while the other lowers cylinder gradually, being careful that the fingers of the other mechanic are not pinched between the rings and lower edge of cylinder. As cylinders are put in place, put nuts on outside and inside hold down studs, but do not tighten down. When all cylinders are in place, put wide base nuts on studs between cylinders. Either of two methods of aligning cylinders may be used, according to the equipment available. If steel straightedges are at hand, it is probably best to align cylinders by that method, but if no straightedge is to be had, they may be aligned satisfactorily by use of the intake manifolds.

### ALIGNING CYLINDERS BY USE OF STRAIGHTEDGE.

Turn cylinder hold down nuts until the cylinders are firmly in place, but not so tight that they can not be moved slightly. Lay straightedge along intake header flanges, with gaskets removed, resting it on the studs. With a thickness gauge, about 0.0015 or 0.002 inch, determine the alignment of each cylinder, by the contact of each header flange with straightedge. It may not be possible to get all six cylinders of each bank absolutely in alignment, but each set of three, 1–2–3, 4–5–6, must line up perfectly, as the intake manifold will be distorted, causing air leaks or damage to the manifold if the alignment is not correct. By tapping on the exhaust header lightly with a rawhide hammer, cylinders may be brought into alignment easily. Tighten down upper and lower nuts, first, taking care not to move cylinders. Before finally tightening all nuts, go over all intake header flanges again, with the thickness gauge, making sure than none have been moved. New type cylinder hold down nuts are plain hexagon, so that it is only necessary to draw them down snugly and with an even tension on all. Old type nuts are castellated, and must be cottered, as they have fewer threads to carry the strain and are more apt to work loose.

### PLACE INTAKE MANIFOLDS.

First see that all gaskets are in place, and in perfect condition, and then see that contact surfaces of intake manifolds are smooth,

and in perfect alignment. Place all four manifolds in their proper places, put on washers and nuts, and tighten up uniformly. Cotter all nuts. Manifold surfaces must be in perfect alignment at points where joint is made with water outlet headers. Lay straightedge of some sort across these surfaces, and make sure that they are perfectly true, as this joint must be water tight, and after intake manifolds are in place and tightened up, they must form perfect contact with water outlet headers. Bring tension on all nuts gradually and evenly so as not to distort the manifolds, and draw up tight enough to prevent leakage, but not so tight as to mash the aluminum flanges. Place gaskets between intake manifolds and water inlet elbows, and secure them with their proper capscrews, drawing down tightly so there is no chance of water leakage. Also make sure that all hose connections are in good condition, taped and shellacked, and clamps drawn up fairly tight. All nuts must be properly cottered, and cap screws all made safe by the use of wire, locking them together in pairs.

### INSTALL WATER-OUTLET HEADERS.

The assembly of two water-outlet headers, hose connections, and extension tube must be put in place at one time. Each header is held by four bolts in addition to two long bolts which support carburetors. Gaskets under headers must be in good condition and nuts drawn down snugly so there is no chance for a water leak. Hose connections must be in good condition, taped and shellaced, and clamps drawn up fairly tight. These outlet headers are interchangeable, so that water outlet may be placed for either front or overhead radiator.

### INSTALL CARBURETORS.

The joint between carburetor and intake manifolds is made secure by the use of two unions, these being in the form of steel collars set into the aluminum, and two copper asbestos gaskets to each carburetor. If possible, use new gaskets each time the motor is overhauled, as an absolutely air-tight joint must be had, and old gaskets become compressed so they are not reliable. Both altitude adjustment and throttle-control rods must be put in place at the same time the carburetors are being installed. Each carburetor is suspended by two long bolts passing between manifolds and through water-outlet headers. Take care that these bolts are started squarely, so as not to strip the threads in carburetors. Float chambers must be placed toward propeller end of motor for proper functioning of carburetors. On the present type of motor, on which we are working, air scoops must be placed with opening toward propeller, but on the later type motors provisions have been made for a drain for gasoline overflow,

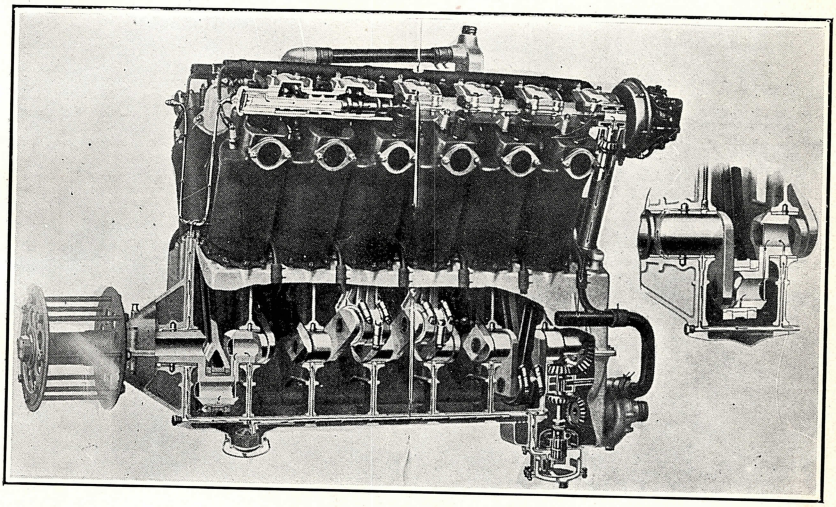


FIG. 23.

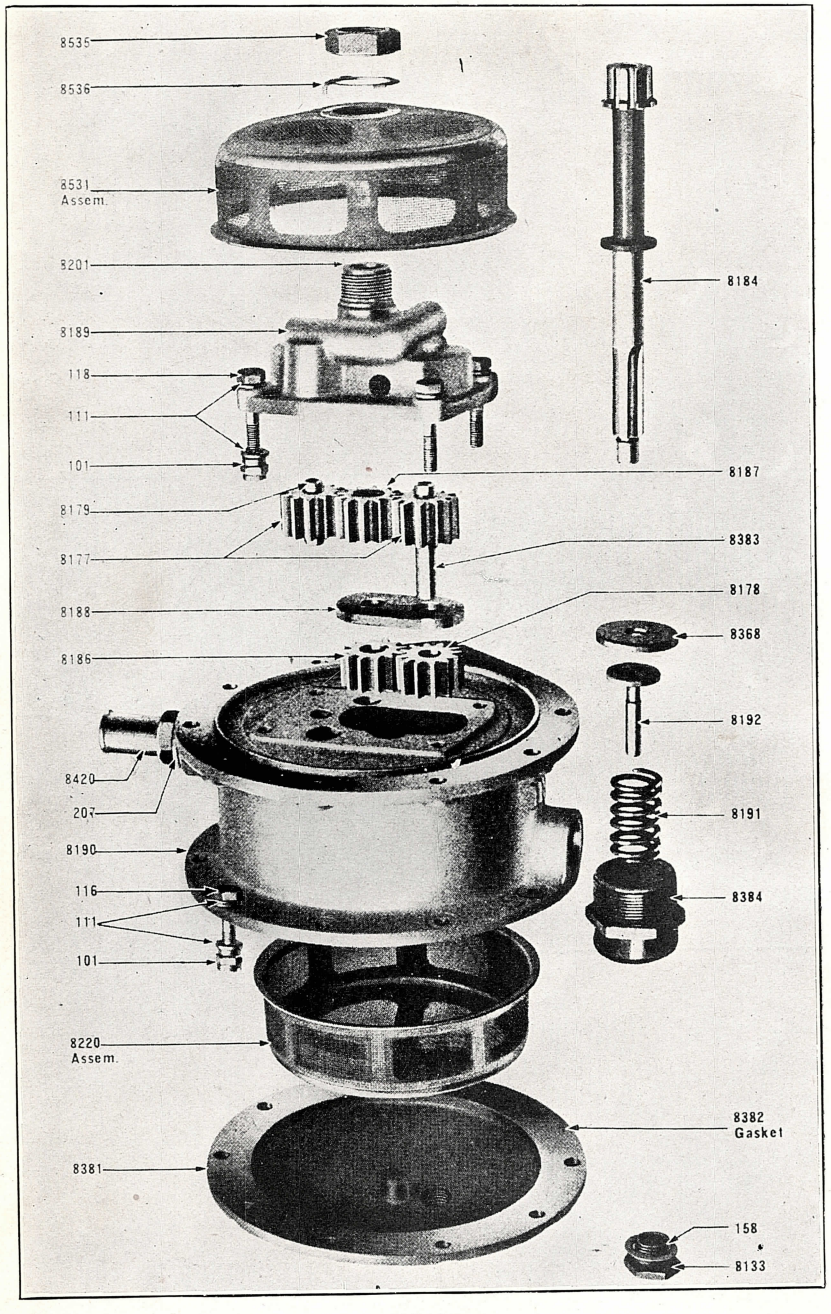

8535
8536
8531
Assem.
8201
8189
118
111
101
8179
8177
8188
8186
8420
207
8190
116
111
101
8220
Assem.
8381
8184
8187
8383
8178
8368
8192
8191
8384
8382
Gasket
158
*
8133

FIG. 24.

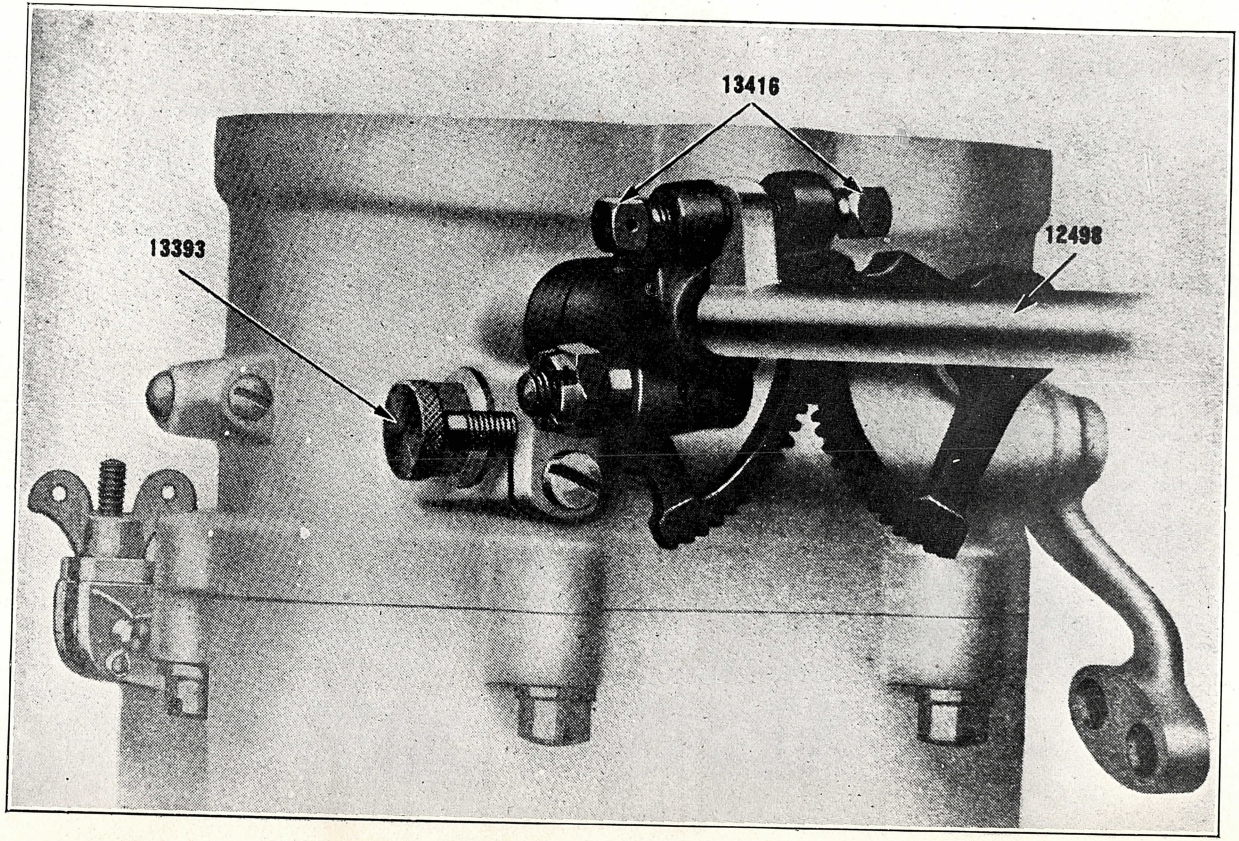



FIG. 25.

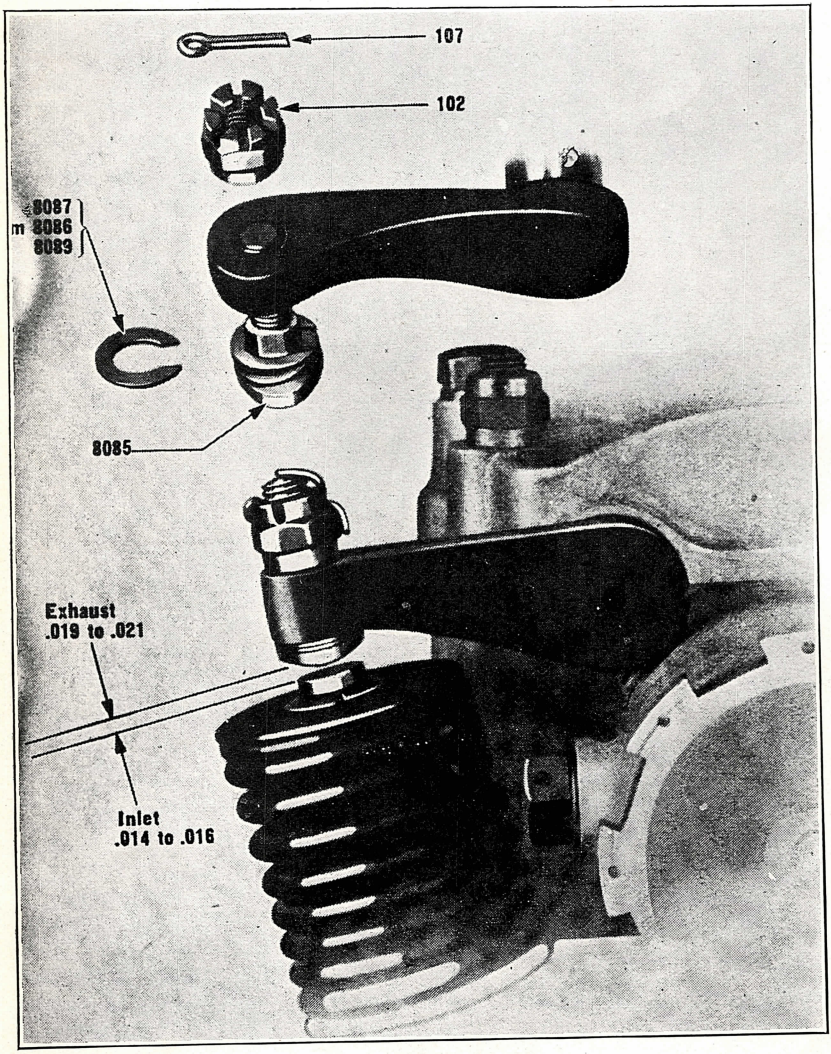

107
102
8087
8086
8089
8085
Exhaust
.019 to .021
Inlet
.014 to .016

FIG. 26.

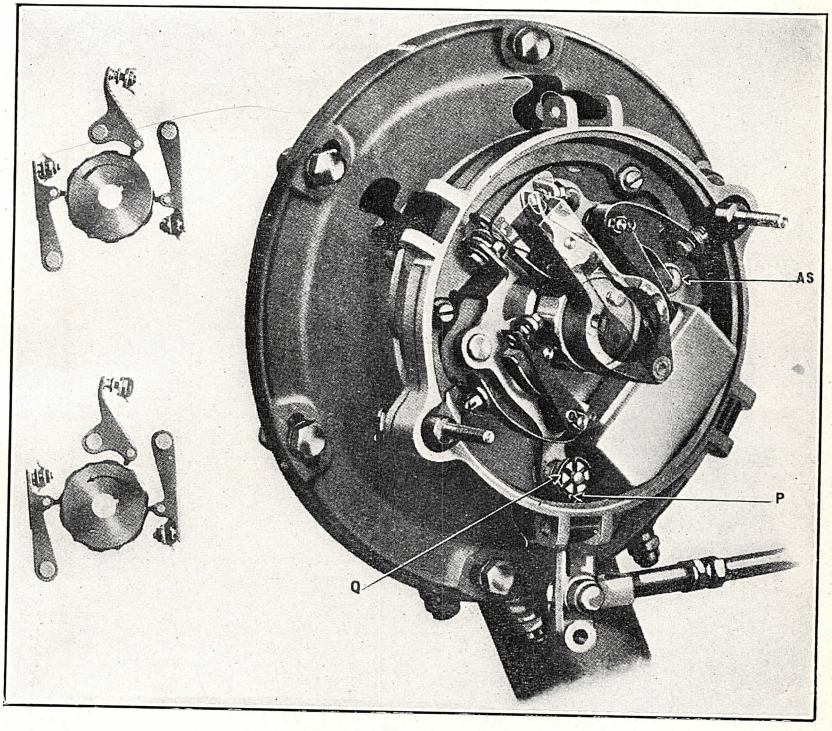



FIG. 27.

and if this drain pipe is not installed now, it must be done as soon as motor is placed in fuselage, to avoid any chance of fire when motor is started. Altitude adjustment rod must be adjusted to length, so that both carburetors will be perfectly synchronized, each opening and closing to the full extent. Throttle-control rod must be adjusted so that two butterfly valves are perfectly synchronized. Provision is made for this adjustment by the use of a coupling with two adjusting screws. Turn out the throttle stop screw on each carburetor until the throttle may be entirely closed. While holding both throttles entirely closed, screw up these coupling adjusting screws until they touch both sides of the lever on throttle-control rod. This is a very important adjustment, and must be very accurately done, otherwise one-half the motor will be receiving more gas than the other, causing very serious consequences.

### INSTALL CAM-SHAFT HOUSING ASSEMBLIES.

As has already been taught, the right and left cam shafts are not alike, so they must be placed on the correct side of the motor. Some mechanics, in assembling a motor, follow marked gears, etc., almost entirely, but such is a very poor policy. The mechanic who overhauls a Liberty motor must know his business well enough to do the assembling and timing without resorting to any such slipshod methods. As no gear markings whatever will be followed, it will be best to put the cam-shaft housing assemblies in place, disregarding all timing for the moment, only making sure that the right and left cam shafts are located properly. See that the packing nuts and washers are on the upper drive-shaft housings. Lower the assembly gradually, holding it square with the cylinders so that the studs will pass freely through the holes See that splines of the upper drive shaft fit into the splines of lower drive-shaft socket without binding, and that drive-shaft housing goes into place freely. Put washers and nuts on all cylinders and cam-shaft studs and draw nuts down evenly. Some of the valve springs will be under compression, which will have a tendency to hold cam-shaft housing up, so make sure that all nuts are drawn down to their proper places. Properly cotter all nuts before going further. Turn down the packing nuts with the spanner wrench provided in tool kit for the purpose, making sure that the felt washers are in good condition and properly placed. Put on cam-shaft oil leads at propeller end of motor, taking care that the tubing is not twisted as couplings are tightened up.

### INSTALL WATER PUMP.

Place new gasket, or one in good condition, over four studs, then place water pump on motor so that the two outlets are pointing

toward opposite sides of the motor. Put washers and nuts on four studs, draw nuts up and try the mesh of water-pump gear with drive gear. Pump cover should be removed for doing this, and allowance should be made for the tightness of pump packing, which will cause pump shaft to turn stiffly. The gear lash should not be less than 0.005 of an inch, nor more than 0.010 inch. If gears mesh too closely, a thin shim placed between pump housing and crank case will remedy it.

### PUT ON WATER INLET MANIFOLDS.

Examine all rubber-hose connections, making sure they are in good condition, then connect manifolds to cylinder elbows. Tape and shellac rubber connections, and draw hose clamps up fairly tight. Next put on manifold extensions, leading from pump outlets, observing the same precautions in regard to rubber-hose connections and clamps.

### PUT ON CRANK CASE BREATHERS.

These must be fitted with gaskets in good condition, nuts drawn up snugly, and cottered. See that screens are in place and cover clips work properly.

### TIMING OF CAM SHAFT.

As all parts of motor have now been assembled except ignition, cam shafts will be timed, and ignition installed. First remove nuts from seven bolts which hold distributor drive flange, and lift off the flange. Special gear puller may then be used to remove the gear from cam shaft. Do not put unnecessary strain on the puller, but turn the screw up gradually, at the same time tapping at several points around the gear. Next turn crank shaft in the direction of rotation until Nos. 1 and 6 left cylinders have their pistons at top dead center. Locate this by the usual method, placing timing disk on the hub flange, and pointers on two front cylinder studs, as explained in the paragraph on "Check timing and Tappet clearances," in Chapter III. Turn crank shaft to point marked "L-6, In. O., Ex. C.," which is 10° past top center. This we will consider the neutral point of No. 1 left cylinder, and the firing point, spark retarded, of No. 6 left cylinder. At this point the exhaust valve should be just closed, and the intake valve just opening, on No. 1 left cylinder, so the crank shaft will be left in this position, and the cam shaft timed to it.

Tappet clearance adjustment will be made by removing or adding shims under tappet head. This may be done by loosening tappet nut, compressing valve spring with a screw driver or other convenient tool, pressing the tappet down and drawing off or putting on the

horseshoe-shaped shims. These shims are of different thicknesses, usually 0.003, 0.008, and 0.015 inch, so that by different combinations any adjustment may be made. Adjust the tappet clearances of No. 1 left cylinder to 0.015 inch on the intake and 0.020 inch on the exhaust, which is an average clearance to work from. This clearance adjustment must be made when the cam shaft is in such a position that both valves are entirely closed, or at about 120° after the intake has closed, which will be about top center on the compression stroke. When these clearances have been obtained turn the cam shaft to the right, which is the direction of rotation, until the point is reached where the exhaust valve of No. 1 cylinder is just closed and intake just at the point of opening. These actions should occur at the same instant, but there may be a movement of 2° or 3° between them. In such a case get the cam shaft at a point midway between exhaust closing and intake opening. Now put the cam-shaft gear in place, making sure that it meshes squarely with drive-shaft gear. By turning it in different positions, one will be found where the teeth will mesh squarely, to within a fraction of a degree. Put in place two or three nuts only, and draw the gear up snugly against the end cam-shaft flange. Before going further check the entire timing of this one cylinder by markings shown on the timing disk, to determine if the cam shaft has been properly set, in relation to the crank shaft. Two things will have to be considered now, to determine this, tappet clearance, and advance or retard of the cam shaft. The tappet clearances were set at only an average figure, which in most cases will have to be changed, at least slightly, so it may be possible that cam shaft is not located correctly. It must be said here that it is seldom possible to get an absolutely correct timing on all valve openings and closings, but the mechanic should endeavor to come as near to the correct point as is possible. Do not be satisfied with the timing until every possible adjustment has been made which will bring it a degree nearer to correctness. An exhaust closing of from 7° to 9° past top center is allowable, if it is impossible to get it exactly correct without sacrificing at some other point. An intake closing of from 40° to 50° past bottom center is allowable, provided it must be done to get the other points correct. Exhaust opening may be as late as 45° before bottom center, if impossible to get it nearer correct without sacrificing at other points. Exhaust opening must never be earlier than 50° before bottom center, which is the correct timing, as an earlier exhaust opening is apt to cause burned or badly warped valves, as well as loss of power. Intake opening must be correct, even if slight sacrifices are necessary at other points. It must be borne in mind that these figures are the maximum limit of variation from the standard timing, and any cam shaft which can not be timed to within these limits is unfit for use. In fact, cam shafts which do not come well

within these limits are not supposed to be passed by factory inspectors, and seldom will one be found which can not be timed much closer than these figures. If a valve is opening early and closing an equal number of degrees early, it will be easily seen that the cam shaft is advanced beyond its proper position. If the same is true except that it is opening and closing late, the cam shaft is retarded in relation to its proper position.

As the cam-shaft gear has 48 teeth, each tooth amounts to $7\frac{1}{2}°$ of cam-shaft travel, or 15° of crank-shaft travel. The gear is held in place by seven bolts, so that a movement of one bolt hole will alter the timing one-seventh of a tooth, which is $1\frac{1}{14}°$ of cam-shaft travel, or $2\frac{1}{7}°$ of crank-shaft travel. As it is only necessary to advance or retard this gear one bolt hole to alter the timing of cam shaft $2\frac{1}{7}°$, a very accurate timing may be obtained by moving the gear the required number of teeth. If a valve opens late and closes early, a like number of degrees, the timing may be corrected by adding shims, thereby reducing the clearance. If a valve opens early and closes late, a like number of degrees, the timing may be corrected by removing shims, thereby increasing the clearance. By using a combination of adding or removing shims, and shifting the position of the gear, a very accurate timing may be quickly obtained. For example, to make this more easily understood, take the following timing and determine what has to be done to correct it:

Intake opens 12° past top center.

Intake closes 49° past bottom center.

Exhaust opens 50° before bottom center.

Exhaust closes 14° past top center.

It will be seen that the intake actions are 2 and 4° late, which will necessitate advancing the cam shaft. As the intake must open at 10° past top center, the shaft may only be advanced 2°, which will be one bolt hole of the gear. This will leave the intake closing about 2° late, but that amount will be allowable. The exhaust will not open at 52° B.B.C., and close at 12° past top center, which leaves it 2° early on the opening and 2° late on the closing. This may be entirely overcome by removing shims, increasing the clearance slightly. All valve actions will then be correct except intake closing, which will be only 2° late. This would be considered a very accurate valve timing. No consideration has been taken of small fractions of degrees, in this case. For all practical purposes, where advance or retard of from 2 to 6° is necessary, a movement of one bolt hole considered as 2°, will be accurate enough. When the left cam shaft has been accurately timed and tested out, on No. 1 left cylinder, turn the crank-shaft 45° in the direction of rotation from neutral point of No. 1 left cylinder. This will bring No. 6 right cylinder on the neutral point, from which the same pro-

cess of timing as has been followed on the left may be carried out. It would seem almost unnecessary to make mention of such trivial point, but many students make a mistake here which must be watched and avoided. As the firing order of motor, beginning with No. 1 left, runs 1L, 6R, 5L, 4R, 6L, 1R, 2L, 5R, 4L, 3R, we have timed No. 1L cylinder first. To carry the firing order out correctly, the right cam shaft must be set in such a position that the neutral point of No. 6R follows 45° after No. 1L. Therefore, make very sure that No. 1L is on the neutral point, and not at the opposite point in the cycle, which is firing point, before turning crank shaft 45° to the neutral point of setting for right cam shaft. When both cam shafts have been properly set and tested out, put on both distributor drive flanges making sure they are properly located. A figure O will be found stamped on the end of cam shaft, where it may be seen when gear is in place, and the figure O which is stamped on the drive flange must be in line with this, to bring distributor finger in line with the segment of distributor leading to the proper cylinder. Draw all nuts up snugly so there is no chance of the gear being out of line, and cotter nuts properly. Now that both cam shafts are properly timed, according to No. 1L left and No. 6 right cylinders, it will be necessary to adjust tappet clearances of all other cylinders. It makes no particular difference on which cylinder the work begins, so long as careful note is made as each cylinder is completed, so that none will be overlooked. As has been stated before, an absolutely accurate timing is practically impossible, but it should be possible in all cases, if the work up to this point has been properly done, to come well within the limits specified. Make sure that all tappet shims are properly placed, with the open sides at various points, and not all on one side, which will cause them to mash down and possibly to work loose. Turn down all tappet nuts snugly, and place cotters very carefully, as the constant vibration is apt to loosen them if they are not drawn up closely in the castellations.

### INSTALLING IGNITION.

It is assumed that the entire ignition system, generator, battery, distributors, and wiring, has been thoroughly inspected and overhauled, and is now at hand to be installed. All breakers should be set with an opening of from 0.010 to 0.013 inch when fully open, on a wide lobe of the cam, and two main breakers of each distributor head must be synchronized, to open not more than 1° apart, and exactly together if possible. The proper location of distributor may be easily determined by letters R and L on the outside surface of the spark-control arms, designating right and left. There is usually a notch on upper side of distributor base flange which is

placed in line with a similar notch on cam shaft housing flange. Rotate crank shaft in the proper direction until the firing point, full retard, or 10° P. T. C., No. 1L cylinder is reached. This will be the same point on timing disk as the neutral point of No. 6L, and the two must not be confused, which may happen if the student's understanding of the timing of cam shaft was not complete. With crank shaft in this position, put on both distributors, placing two bolts in each as temporary fastening. In case there are no notches to follow, place the distributor head in position over two terminal posts, and note position of segment marked 1L, in relation to the distributor arm or rotor. This should point upward, nearly in line with the center line of the cylinder, at full retard. This is true of both left and right distributors. By leaving the two bolts slightly loose, the distributor may be moved either way for several degrees, making it possible to get a very accurate spark timing, and to synchronize both distributors perfectly. A battery and lights should be used, to accurately synchronize the distributors, but in the absence of this, the ordinary method, using thin paper, may be used. If lights are used, both distributors must be so adjusted that both lights will go out at the same instant, at 10° past top center. with spark-control arms in full retard position. If papers are used, both papers should be placed between main breakers of each distributor which are known to open last, and when the crank shaft is brought up to 10° past top center, the papers should be released by contacts, at the same instant, and from 10 to 11° past top center. It must be fully understood that both distributors are placed while crank shaft is in the one position, as each one is firing a separate plug in the same cylinder, at the same instant. The total spark range from full retard to full advance is 40°, so that when the distributors are set at 10° full retard position, the full advance should be 30° before top center. When both distributors are in their proper positions, tighten all bolts and install the cross reach rod, between two spark-control arms, in such a way that both distributors will move together from full retard to full advance, testing the synchronization of breakers at both points, to make sure they are absolutely correct. When this has been done, put all remaining bolts in place through flanges, draw nuts up snugly, and cotter them. Put distributor heads in place, right side up, which may be easily determined from lettering stamped on them, and from No. 1 left, which is at the upper side. It makes no particular difference whether a certain distributor head is placed on the right or left side of the motor, as both are exactly alike, but it is important that they are not placed upside down, which would reverse the coils and put the system out of commission. Care must be taken in placing the distributor heads on the distributors, as rotor brushes are easily broken. It is best to

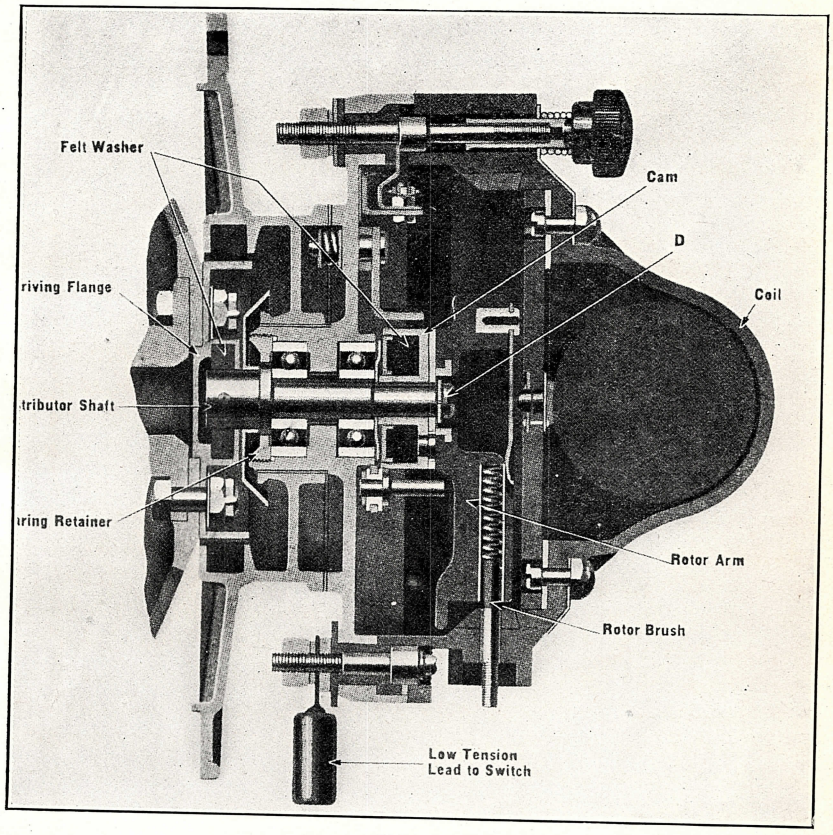

Felt Washer
Cam
D
riving Flange
Coil
tributor Shaft
ring Retainer
Rotor Arm
Rotor Brush
Low Tension
Lead to Switch

FIG. 28.

have motors in a vertical position to the center line of two terminal studs, placing distributor heads on two terminal studs and rocking back and forth, which will tend to push rotor brush back out of the way without its being broken off. Generator should now be put in place, making sure that splines of shaft and socket go together freely. Put washers and nuts on three studs through base flange, draw nuts down snugly, and cotter them. Next install the cable

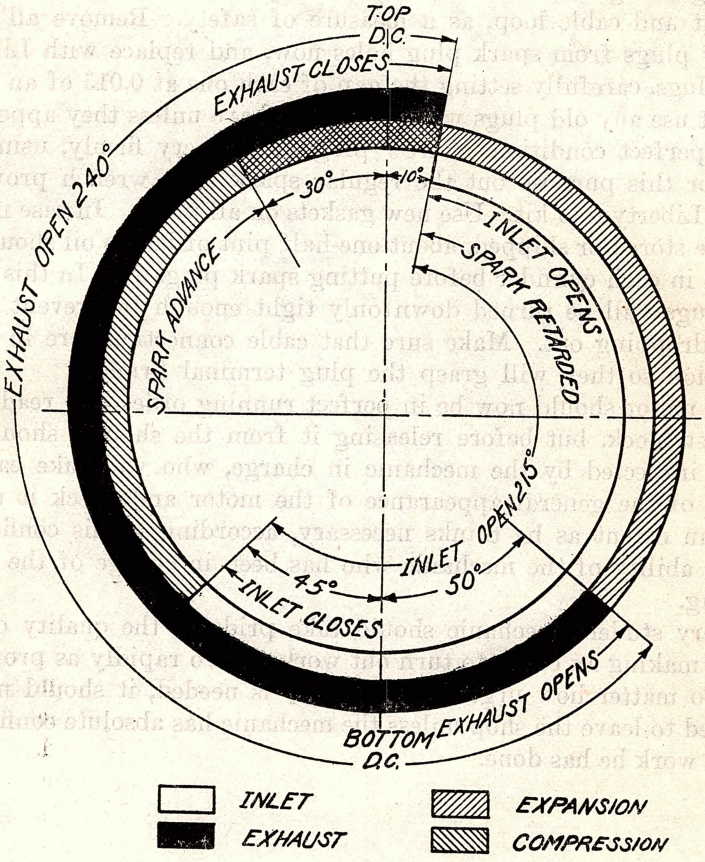



FIG. 29.

tube, by screws through tube clips into intake headers, making sure that tube is placed right side up.

The small bakelite plate through which all cables pass after leaving the tube has cylinder numbers plainly marked for each cable, but it is best to test out each one carefully with a buzzer or light as some new cables may have been placed, and not properly located. Connect all cables to their proper terminals on the distributor heads, noting that all cables leading to plugs on one side cylinders, toward

propeller are conected to the left distributor, while those leading to plugs toward gear end of motor are connected to the right distributor. Place cables in such positions that they will not be cramped or stretched by advance and retard movement of the distributor heads, as they are very easily broken off just inside the rubber covering, at the end of tubing which forms the terminal loop, if not properly placed.

A lightweight split washer should be placed between each terminal nut and cable loop, as a measure of safety. Remove all temporary plugs from spark plug holes now, and replace with Liberty type plugs, carefully setting the gap of each one at 0.015 of an inch. Do not use any old plugs which you may have unless they appear to be in perfect condition. Screw plugs down very firmly, using no tool for this purpose but the regular spark plug wrench provided in the Liberty tool kit. Use new gaskets on all plugs. In case motor is to be stored or shipped, about one-half pint of heavy oil should be placed in each cylinder before putting spark plugs in. In this case, the plugs will be turned down only tight enough to prevent them from dropping out. Make sure that cable connections are in good condition so they will grasp the plug terminal firmly.

The motor should now be in perfect running order and ready for the test block, but before releasing it from the shop it should be again inspected by the mechanic in charge, who will take careful notice of the general appearance of the motor and check it up to such an extent as he thinks necessary, according to his confidence in the ability of the mechanic who has been in charge of the overhauling.

Every student mechanic should take pride in the quality of his work, making an effort to turn out work, not so rapidly as properly, and no matter how urgently the motor is needed, it should not be allowed to leave the shop unless the mechanic has absolute confidence in the work he has done.

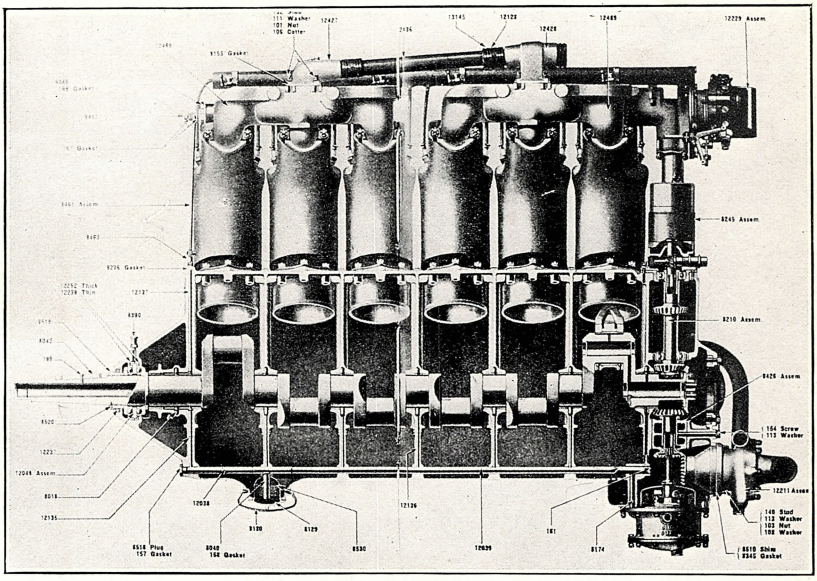

111 Washer
101 Nut
106 Cotter
12427
13145
12128
12428
12485
12229 Assem.
9153 Gasket
8245 Assem.
8236 Gasket
8390
8210 Assem.
8426 Assem.
8520
164 Screw
113 Washer
12211 Assem.
12135
12038
12126
148 Stud
112 Washer
103 Nut
106 Washer
8129
8130
12035
8174
8518 Plug
157 Gasket
8040
158 Gasket
8518 Shim
8345 Gasket

FIG. 30.

## Chapter V.

## THE LIBERTY STARTER.

The Liberty starter is a four-cylinder racial two-cycle air motor and compressor, with a bore of 2¼ inches and stroke of 2¼ inches. As a starter it has 9 to 1 gear reduction on final drive to motor. It pumps direct drive at engine speed.

The valve construction is a semirotary of the Corliss type, having universal joint action to rocker shaft. The driving member between the rocker shaft and the valve not only performs the function of a universal joint, but is so constructed that the air pressure in valve chamber presses it against the end of rocker shaft bearing sealing the chamber air-tight. It also permits the valve to be floated and held against the seat by the air pressure. This entirely eliminates the use of troublesome soft packing where valve actions are used.

The crank shaft is carried on roller bearings. All parts are idle except when brought into action as a pump or a starter.

The Liberty starter has been approved and is being used by the United States Navy. The Japanese Government recently placed an order for a large number.

The usual attachment on such as the Liberty, Hall-Scott, Renault, and Bugatti motors is by bolting direct the flange of starter to the flange on motor. A suitable flexible coupling is provided for the drive to the crank shaft. Where flanges are not provided, such as the Curtiss V. X., etc., arms are provided for supporting the starter on engine runners.

Although it weighs but 30 pounds complete the Liberty starter is capable of starting the largest engines in service, such as the Liberty, Hall-Scott, Renault, Bugatti, etc. Its compactness lends itself to the requirements of installation on aeroplanes where but little space is available for accessories of any kind; though the Liberty can hardly be termed an accessory, for it has really become a necessity.

Its length is only 8 inches. It cranks the engine at 150 R. P. M. or more, and it replenishes its own energy in half a minute. The tank weighs 12¼ pounds, bringing the total weight of the outfit to 49 pounds.

After the engine is started, the Liberty starter automatically disengages and remains disengaged until it is needed again either as a starter or compressor.

When the air pressure in the tank becomes low the compressor is put in operation by pressing a button on the control valve while the engine is running at low speed. When engaged the engine must be run at from 1,200 to 1,400 R. P. M., and when the pressure has been brought up to 230 pounds the mechanism automatically becomes disengaged.

Hundreds of these starters are in service throughout the country, and the new mail service is installing them in the larger machines.

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